# STUDIES ON SPONTANEOUS HEATING LIABILITY OF SOME INDIAN COALS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

**BACHELOR OF TECHNOLOGY**

**IN**

**MINING ENGINEERING**

BY

**RANJAN KUMAR SAHU**

110MN0402


**DEPARTMENT OF MINING ENGINEERING**

**NATIONAL INSTITUTE OF TECHNOLOGY**

**ROURKELA-769008**

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# NATIONAL INSTITUTE OF TECHNOLOGY

# ROURKELA

# CERTIFICATE

This is to certify that the thesis entitled "**STUDIES OF SPONTANEOUS HEATING LIABILITY OF SOME INDIAN COALS**" submitted by **Sri Ranjan Kumar Sahu** in partial fulfilment of the requirements for the award of Bachelor of Technology in Mining Engineering at the National Institute of Technology, Rourkela is an authentic work carried out by him under my guidance and supervision.

To the best of my knowledge , the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

**Dr. B.K.Pal**

**Professor**

**Department of Mining Engineering**

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I would take the opportunity to thank my seniors Sri Vikrant dev Singh, Sri Nishant Pati for helping me in collection of coal samples. I acknowledge my indebtedness to all of them whose works have been referred in understanding and completion of this project.

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Ranjan Kumar Sahu

Date :

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# ABSTRACT

Spontaneous heating ultimately leading to coal mine fire pose a major problem and has been an area of concern in mining industry since long. It has drawn the attention of industry as well as researchers to investigate regarding its cause and determine the susceptibility of various coal seams to spontaneous heating. Majority of coal mine fires existing in different coalfields are primarily due to spontaneous combustion of coal. Generally mine fires start very small but gradually it expands to a large scale and causes immaculate loss of natural assets causing pollution of land, water ,air along with huge economic losses to the concerned organisation. Although extensive research work has been done on this topic but proper assessment and determination of liability of various coal types to spontaneous combustion is necessary in dealing with such problems before, during and after mining. It would help the mine operators to plan the extraction and working of coal before spontaneous combustion takes place. Hence, determination of spontaneous heating liability of coal samples is essential to plan the production activities and suitably optimise it in order to do complete extraction within incubation period and prevent mine fire and its losses.

This project deals with the study of determination of spontaneous heating liability of coal and its variation with respect to the coal properties. Eight coal samples were collected from different collieries across India: Mahanadi coal fields (MCL), Bharat coking coalfield Limited (BCCL), Singreni Collieries Company Limited (SCCL), South Eastern Coalfields Limited (SECL), North Eastern Coalfields Limited (NECL), Western Coalfields Limited (WCL) and were subjected to different experimental techniques for assessment of their spontaneous heating liability.

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# Chapter 1

# INTRODUCTION

General

Objective

# 1.INTRODUCTION

## 1.1 GENERAL OVERVIEW

Coal mine fire is one of the key issues in the coal mining industry in India as well as abroad. Continuous research work and analysis has concluded that major part of the mine fire is due to the soul reason of spontaneous heating. It accounts for a huge loss of beyond 300MT of per year across the globe.

Spontaneous combustion of coal refers to the process of self heating followed by getting oxidised in a self propellant manner resulting in ignition without any external source of heat. Coal when exposed to air, it absorbs oxygen and evolves heat. All types of coal generally absorb oxygen and oxidise to evolve co, $CO_2$, and $H_2O$ along with heat. This heat slowly dissipates into air. If the rate of oxidation is slower and the amount of heat dissipation is higher than the amount of heat accumulation then coal doesn't reach ignition temperature (Critical Temperature for Oxidation) and the process is referred as weathering. But in case the oxidation rate is faster and the amount of heat accumulation is higher than the amount of heat dissipation ,it makes the coal reach the critical temperature for oxidation resulting in coal ignition which is referred as Spontaneous combustion.

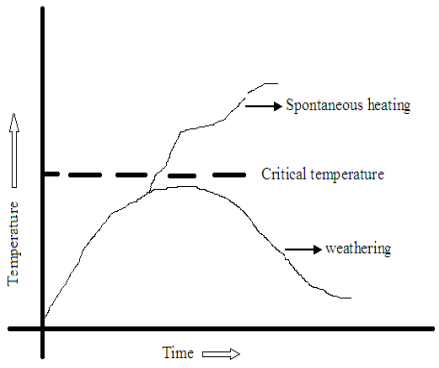



Fig no 1.1.1 Curve showing Difference between Spontaneous heating and Weathering

Spontaneous heating results in serious accidents causing environment pollution, considerable economic losses, loss in property and life etc. Spontaneous heating in any area of a mine affects working of other portions of the mine causing ventilation problems due to evolution of anoxic gases. Past studies on this topic reveals that most of the mine fires resulting from spontaneous heating could have been avoided if necessary arrangements had been done. Therefore there is a need of assessment of the susceptibility of various coal towards spontaneous heating and its liability along with its risk rating for quantified extraction of coal.

Different coal producing countries use various different methods to determine spontaneous heating tendency of coal viz. 1. Crossing Point Temperature in India , 2.Olpinski Index in Poland, 3.Russian U- Index in Russia, 4. Adiabatic calorimetry in U.S.A etc. Apart from this various recognised researchers adopted different methods for studying the spontaneous heating liability of different coal samples. Few of those methods are:

1.Wet Oxidation method (Singh et al., 1985; Tarafdar and Guha, 1989).

2.Differential Thermal Analysis (Banerjee and Chakravarty, 1967; Gouws and Wade, 1989a)

3.Gas Indices studies (Panigrahi and Bhattacharjee, 2004; Singh et al., 2007)

Despite of continuous research work there has been no single conclusive specific method suggested by researchers for determination of spontaneous heating liability of coal samples. Therefore, it is been considered that a number of methods need to be carried out in order to conclude with fair accuracy.

## 1.2 OBJECTIVE OF THE PROJECT

1. Collection of samples from diversified coal fields.

2. Determination of Intrinsic Properties along with Calorific values of the different coal samples.

3. Determination of liability index, WITS-EHAS index of the coal samples and its risk rating by carrying out various experimental techniques as Crossing Point Temperature, Flammability Temperature, Wet Oxidation Potential Difference method.

4. To correlate various susceptibility indices with the intrinsic properties of coal and identifying the property which hints majorly at the spontaneous heating tendency of the coal samples.

# Chapter 2

# LITERATURE REVIEW

# 2.1 LITERATURE REVIEW

The following is the brief overview of the various research work done by different researchers in order to determine the liability of coal samples to spontaneous heating and their observation regarding the same.

**Mahajan,Tomita and Walker(1976) –** They used DSC technique and reported DSC curves for 12 coal samples of various ranks in a helium atmosphere at a flow rate of 1ml/min and a temperature range of 100 to 580 °C at a constant heating rate of 10 °C/min. Samples of around 12 -20 mg was used with reference material being alumina. They concluded that the thermal effects of coal, ranging in rank from Anthracite to Bituminous were endothermic in nature. In case of only Sub-Bituminous coal & Lignite exothermic heat was observed.

**Feng et al(1973) –** methodised a composite Liability Index by using various results of CPT(Crossing Point Temperature), called FCC Index.FCC Index was calculated as per the equation:

$$\text{FCC Index} = \frac{(\text{Average heating rate between 110 }^{o}\text{C and 220 }^{o}\text{C} * 100)}{(\text{Relative Ignition Temperature})}$$

The lower limit was set to 110°C (Heating rate) in order to ensure that all moisture had evaporated from the sample.

The upper limit of 220°C was chosen in order to ensure there would have been a little evolution of Volatile matter below this temperature.

**Gold(1980)-** demonstrated the occurrence of exothermic processes associated with the involvement of Volatile Matter in or near the plastic region of the samples. He concluded that the temperature and the magnitude of the exothermic peak were strongly affected by the particle size ,heating rate and the sample mass.

**Banerjee and Chakraborty(1967)-** suggested DTA(Differential Thermal Analysis) for the study of spontaneous combustion of coal, generally in classifying coal depending upon their susceptibility to self heating. They prescribed particular steps for DTA studies and recommended Calcined Alumina as reference material for DTA experiments. Heating Rate was maintained at 5 °C/min. Typical temperatures obtained from various coals were included in this phenomenon to explain self heating process.

**Mahadev and Ramlu(1985)-** proposed an Index known as MR Index and objected to the arbitrary selection of temperature range in the FCC Index.

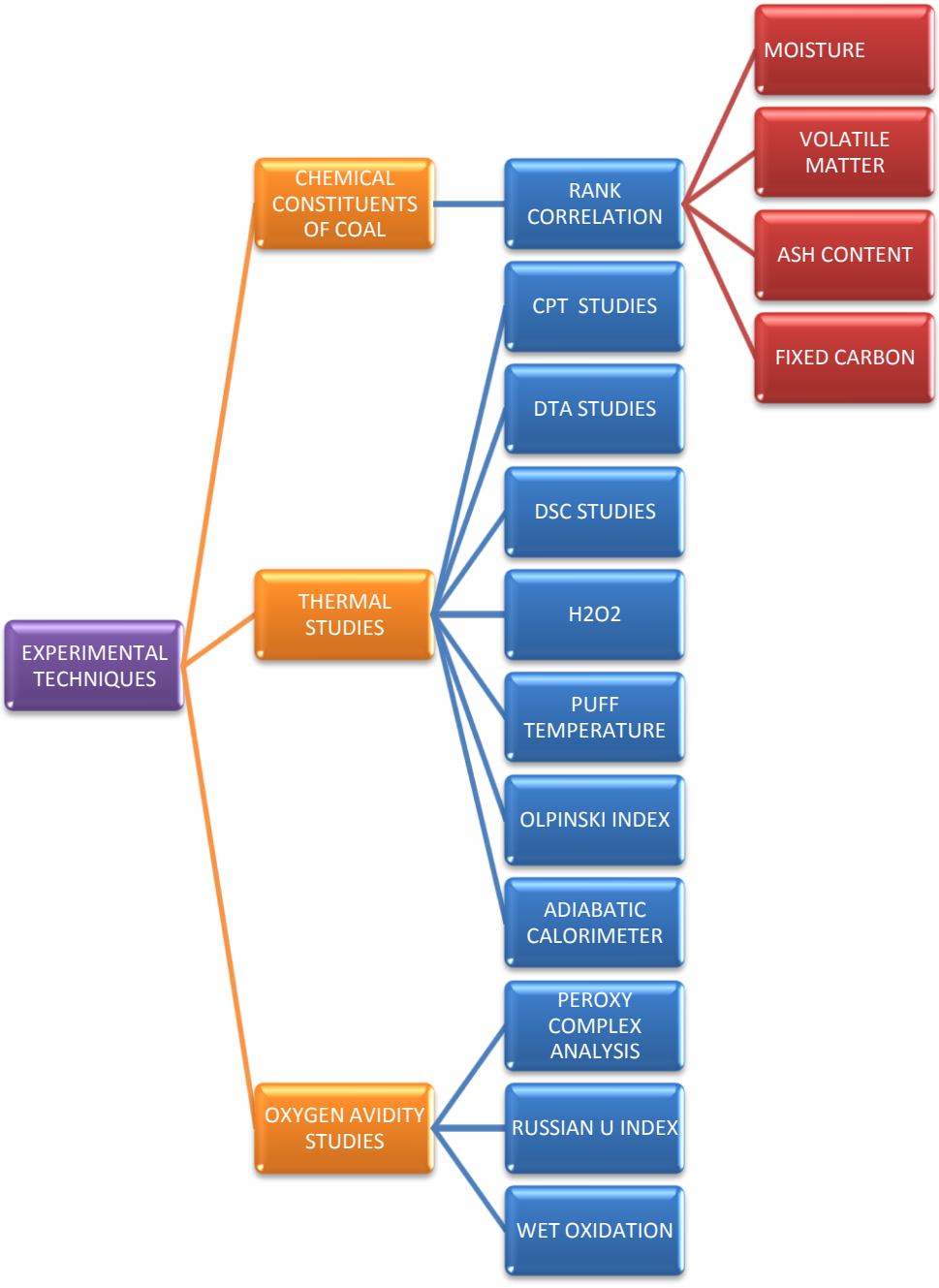
$$\text{Liability Index} = \frac{\text{Heating rate at CPT* Time taken to reach the Inflexion point * 10)}}{\text{(Time taken to reach the CPT* Average Heating Rate between the Inflexion point and Crossing point)}}$$

Reciprocal of the Liability Index was found to be increasing with Self Heating Liability.

**Tarafdar & Guha(1989)-** reported the results of Wet Oxidation of coal be Alkaline Permanganate Solution involving measurement of differential temperature at different base temperature, at a constant heating rate. They experimented 7 samples of known CPT by Wet Oxidation Method & then found out a correlation between CPT values & the corresponding differential peak temperatures, and between CPT & the observed Potential changes.

They suggested that Potential Difference measurements during Wet oxidation of coal and the differential temperature may be used as alternative techniques for the assessment of liability towards spontaneous heating.

**Banerjee(1985)-** observed various experimental techniques available worldwide to assess and analyse spontaneous heating susceptibility & summarised and organised them as follows:



**Panigrahi et al.(1997)-** They conducted experiments on 10 coal samples from Jharia. The Carbon, Hydrogen, Nitrogen & Sulphur contents of these samples were determined by Fenton's method of Ultimate Analysis. CPT of above samples were also determined & attempts were made to correlate the Russian Index & CPT of coal samples with its basic constituents viz. Carbon, Hydrogen and Ash Content and was categorised as a handy method of coal categorisation in Indian Context from the point of Susceptibility of Spontaneous Combustion.

**Bannerjee(1972)-** conducted CPT analysis of a number of Indian coal samples. He stated that coals with Crossing Point Temperatures between 120°C & 140°C can be categorised as highly susceptible to spontaneous heating. Coal samples with CPT from 140°C to 160°C can be categorised as moderately susceptible ones and those above 160°C are poorly susceptible.

**Nandy et al.(1972)-** correlated the variation in Crossing Point Temperature values with the Volatile Matter, Oxygen Percentage & the moisture content of coal. He observed that CPT was inversely proportional to the above components. But beyond 4 to 6% moisture content,35%V.M there is not much change in CPT values. Generally above 4 to 6% moisture content in coal, CPT shows a rising trend.

Hence ,it could be noticed from the above reviews that there is no universally accepted method for determining the spontaneous heating liability of various coal samples.Thus it was decided to carry out different experimental techniques to reach a clear conclusion viz. Wet Oxidation Potential Difference Analysis, Flammability Temperature Analysis, Crossing Point Temperature Analysis in order to accomplish the objectives of this present dissertation work.

# Chapter 3

# MECHANISM OF SPONTANEOUS HEATING OF COAL

Mechanism of Spontaneous Heating of coal.

Factors affecting Spontaneous Heating Liability of coal.

Theories on Spontaneous Heating

# 3.0 MECHANISM OF SPONTANEOUS HEATING OF COAL

## 3.1. MECHANISM:

Coal is a stratified organic heterogeneous rock with carbon content varying from 95% in Anthracite to 60% in Lignite stage(young coal) with Bituminous and Sub Bituminous in between. The automatic oxidation of coal is a complex physio- chemical process accompanied by the absorption of oxygen followed by formation of coal oxygen complex and further its decomposition to liberate heat. Because of the enormous diversity of composition of mineral matter in coal the complexity of the above process is tremendous. Various overlapping simultaneous reactions do take place during oxidation of the heterogeneous coal mass. Generally the proneness of coal to auto oxidation is proportional to the rate of oxidation of coal at ambient temperature. This low temperature aerial oxidation consists of various structural alteration of the coal mass resulting in the formation of numerous stable chain reaction due to large number of oxidation states of carbon followed by formation of a variety of strong carbon oxygen bonds. The observable, structural and compositional changes hint that the above process is a time dependent dynamic process. The entire process is heterogeneous:

1. Intrinsically- due to presence of two phases: solid and gas.
2. Extrinsically- due to diversified structural changes.

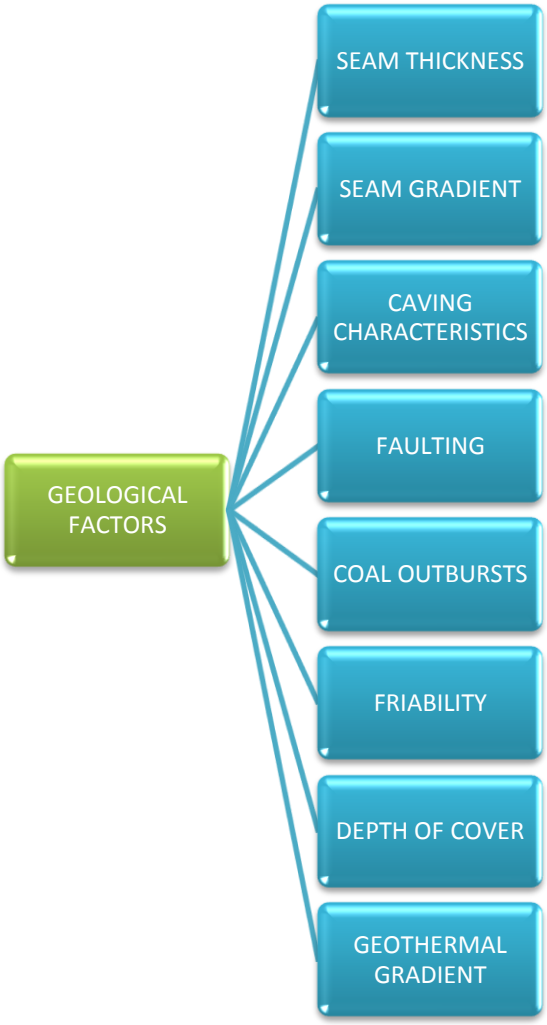
Generally coal gets heated up when it absorbs oxygen and the decomposition procedure can be explained as follows:

The rate of oxidation is petty sluggish below 50°C and it accelerates above 50°C but after it crosses 80°C a steady state is attained for a short interval of time probably due to removal of moisture. Following it removal of oxides of carbon begins at 120°C. The rate of interaction of

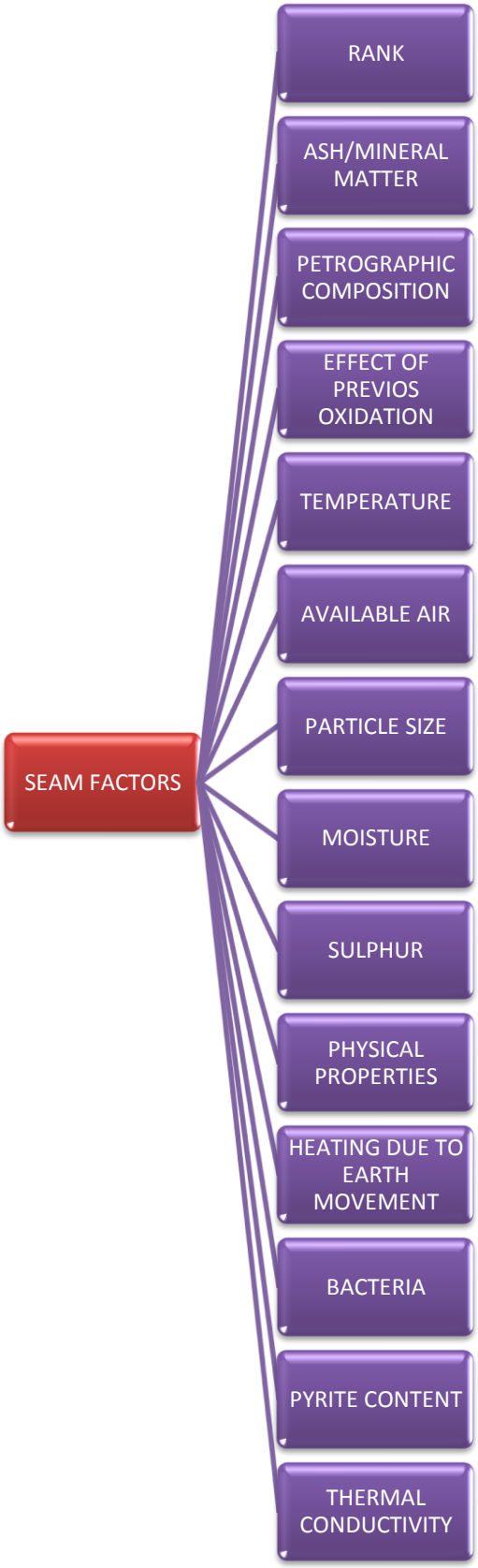
oxygen with coal accelerates up to 180°C and next to decomposition starts between 120°C and 180°C. Finally the self sustained process of combustion begins somewhere around 220°C to 275°C with erotic rise in temperature until ignition point is reached.

## 3.2. Factors affecting spontaneous heating of coal

There are numerous methods which affect the Spontaneous heating of coal. The classification of the factors as per categories is as follows:




MINING FACTORS
MINING METHODS
RATE OF ADVANCE
PILLAR CONDITIONS
ROOF CONDITIONS
CRUSHING
PACKING
EFFECT OF TIMBER
ROADWAYS
LEAKAGE
MULTI SEAM WORKINGS
COAL LOSSES
MAIN ROADS
WORKED OUT AREAS
HEAT FROM MACHINES
STOWING
VENTILATION PRESSURE
BAROMETRIC PRESSURE
CHANGE IN HUMIDITY


SEAM FACTORS
RANK
ASH/MINERAL MATTER
PETROGRAPHIC COMPOSITION
EFFECT OF PREVIOS OXIDATION
TEMPERATURE
AVAILABLE AIR
PARTICLE SIZE
MOISTURE
SULPHUR
PHYSICAL PROPERTIES
HEATING DUE TO EARTH MOVEMENT
BACTERIA
PYRITE CONTENT
THERMAL CONDUCTIVITY

### 3.2.1. GEOLOGICAL FACTORS

**Seam thickness:** whenever the seam thickness is more than the parts of the seam which can be mined in one go, such an area is more susceptible to spontaneous heating because the un-mined area will be exposed to a sluggish ventilation flow. It was found that spontaneous heating was invariably dependent on the method of working, friability of coal, type of ventilation and thickness of the seam. Generally the bands present with section of thick seam are more liable to spontaneous heating. The more thicker the seam, it becomes more difficult to avoid leaving high risk coal within the goaf region. Precisely, it is advisable to do selective mining in order to leave the lowest risk coal as waste. But such a thing is not always practically possible. On few occasions a coal floor or roof can be left un-mined where:

- The natural roof or floor tends to be weak.
- The seam is thick.
- Presence of inferior coal below or above the mined area.

**Seam gradient:** Seams which are flat in gradient are less prone to spontaneous heating. But in case of steeper seams there arises convection currents due to difference in temperature leading to air currents in the goaf region. Also within the extracted areas there may be flow due to buoyancy due to difference in densities of methane, carbon dioxide, nitrogen at different elevation leading to flow of air influencing the development of spontaneous heating in waste, goaf or old workings.

**Caving characteristics:** In mines where partial extraction is done leaving sufficient pillars behind to support the super incumbent strata , the caving characteristics are of least significance. But in such a situation it is desirable to fill the waste as fine material in order to reduce the amount of leakage air flow within the region of extraction. Thus the falling material occupies the

maximum possible volume in order to fill the void created. It should be kept in mind the friable strata to fall should not be of carbonaceous type as it may lead to spontaneous heating and catching of fire of the left over pillars. Thus in such case the pillars should be extracted judiciously in order that the entire strata caves down.

**Faulting:** Spontaneous combustion is immensely influences by faulted ground. The grinding action along the fault plane with the fine coal formations may lead to spontaneous combustion. Faults generally slows down the pace of face advance leading to attendant risk of heat development.

**Coal outbursts:** It is majorly found in hard coal formation rather than soft and low grade coals. In coal outbursts generally fine coal is formed and is thrown away which might lead to passing of it through any place of active heating resulting in spontaneous combustion. Chances of coal outbursts are more with increasing depth. Factors associated with outbursts of spontaneous heating are:

1. Volcanic acivities
2. Mining method
3. Geological conditions
4. Characteristics of roof and floor
5. Characteristics of rock and coal
6. Contained gas
7. Overburden stress
8. Permeability of the gas reservoir

**Coal friability:** Friable coals expose larger surface area resulting in higher rate of oxidation tending to achieve more heat per unit volume.

**Depth of cover/Geothermal Gradient:** With increase in depth, the natural strata temperature increases along with the in-situ base coal temperature. The geothermal gradient is 40 metre per degree centigrade. Thus high depth ensures high temperature of exposed strata after extraction which might lead to increased susceptibility to spontaneous combustion.

### 3.2.2. MINING FACTORS

**Mining methods:** Advancing long wall mining method leaves an extracted area lying between the entries to serve the working places. Generally the creation of ventilating pressure difference encourages air to pass though these areas leading to chances of spontaneous heating. Retreating system of extraction avoids above problem in cases where continuous stowing is done along with the advancement of the coal face, except the case when bleeder entry system is made to ventilate the waste.

**Rate of advance:** There is always entry of air to waste areas in close proximity to the working face by ventilating pressure or by bleed action. In such cases the rate of flow at times may be critical. So generally in a working face a piece of coal is exposed to air for the time period required in the advancing of the face. This time should not be excessive in order to avoid spontaneous heating.

**Pillar size:** It has a direct impact on liability of coal to spontaneous heating. Pillars should be of optimum size in order to avoid crushing at the edges leading to spontaneous heating. The depth of cover, strength of coal and other parameters determine the size of coal. Also crushing of pillars is another sign of methane emission and spontaneous heating.

**Roof conditions:** Poor roof generally allow shock waves to pass through it subsequently leading to have cracks within it. As a result the fallen areas of the roof are supported by timber supports.

These cavities accumulate methane which acts as a source of ignition after localised spontaneous heating.

**Crushing:** It is primarily found at pillar edges and at worked out areas. As a result of crushing at pillar edges it may lead to leakage paths via itself tending to interaction of loose coal with air and may lead to auto oxidation. Also in worked out areas loose coal is present due to spalled pillars or roof falls and sluggish ventilation at such places may lead to spontaneous combustion.

**Packing:** Low quality packs often used in coal mines pose a big threat and are more liable to spontaneous combustion.

**Effect of timber:** In past generally timber props or other timber equipments were generally found in close proximity to spontaneous combustion regions, which gave rise to a school of thought that timber, is responsible for spontaneous heating.

**Roadways :** Roadways always pose a sign of threat and mostly leads to spontaneous combustion due to availability of loose coal as well as leakage air is available which adds up to auto oxidation of coal. More the amount of exposed coal more are the chances of liability of spontaneous heating. The common points of such incidents are:

1. Juntions
2. Air Crossings
3. Doors, Regulators, Connecting roads
4. Obstruction in roads
5. Old roadways

**Leakage:** For spontaneous heating to take place there must be a steady supply of oxygen and an area should be available where a build-up of heat is possible. Such a case is attained by air leaks through fissures available in solid coals resulting in shallow –seated heating circumstance.

Above situation is found when leakage paths are available around air regulators, doors, air crossings etc or elsewhere high pressure gradient is available across the stopping's leading to drivage of air across it.

**Multi seam workings:** In case of multi seams where an un- mined seam is available underneath another totally mined seam, it may lead to a situation where leakage of air may be from upper seam to lower seam leading to spontaneous heating chances of un-mined underlying coal seam.

**Coal losses:** Basically all mining methods lead to spillage of some remmant coal.It is never possible to extract 100% of coal by any mining method. So if there is availability of air and there is presence of some remaining crushed waste coal and there also exists a place where potential accumulation of heat is possible then it may pose a major threat resulting in spontaneous combustion.

**Working out areas:** Within the area of ventilating air-screen worked out areas pose a potential area for spontaneous combustion. Also addition of heat by working of machinery may demand additional air to be circulated requiring a high ventilating pressure with consequently increased risk of leakage.

**Stowing:** It is an weapon to control spontaneous combustion by sealing off the extracted area.

**Ventilating pressure:** In any mines the flow of air is generated by creating pressure difference. Such pressure difference are created by mine fans or by natural ventilation, but the distribution of pressure is primarily dependent on the distribution of the air quantity and resistance of the various mine paths. Wherever there is a pressure difference it leads rise to leakage or flow of air via strata or pillars etc. Thus ventilating pressure is one of the prime causes of spontaneous heating.

**Barometric pressure:** Generally air at any cost finds a way into a sealed –off area as a result of the underlying cases:

1. Barometric changes.

2. Continous leakage resulting from a pressure difference between the intake and return stopping's.

3. Fluctuations in ventilating pressure resulting from the opening of doors and the movement of cages and mine cars.

**Humidity :**It is the property of coal to absorb moisture and when it does so from the ventilation air it gets heated up due to release of latent heat of condensation and due to chemisorptions effects and the reverse happens when it losses moisture by evaporation. Thus humidity plays a major role in case of any misbalance.

### 3.2.3. SEAM FACTORS

**Rank:** The rank of coal is a function of the original plant debris from which it is formed and the amount of it has undergone. The increase in carbon content and decrease in oxygen content signifies high rank coal. Basically high rank coals oxidise very slowly in comparision with low rank coals. Low rank coal poses more prone to spontaneous heating.

**Petro graphic composition:** Various petro graphic tests do suggest that fusain is least reactive, and Durain is more reactive than Vitrain. Calculations of the reaction velocities of exinite,inertinite and vitrinite do suggest that beyond 165 degree Fahrenheit exinite has a much higher oxidation rate than others. Hence a quantitative count of macerals may help in determining susceptibility of coals towards spontaneous combustion.

**Temperature :** With increase in temperature, the rate of absorption of oxygen increases substantially. With every 18 degree Fahrenheit rise in temperature the average rate of oxidation doubles.

**Available air:** In case of inadequate availability of oxygen, the rate of oxidation is very slow and there is no appreciable accumulation of heat. In case if the rate of air flow is high then the oxidation rate rises but at the same time the accumulated heat gets carried away by the flowing air. Thus if the flow rate is optimum then at that time it comprehensively supports spontaneous heating.

**Particle size:** Powdered coal poses more threat than solid coal. Solid coal has low permeability to allow passage of air through it. Thus small particles will show more proneness to spontaneous heating.

**Moisture: Its** effect is uncertain. Presence of moisture in small quantity adds up to spontaneous heating rate but large amount of moisture retards spontaneous heating rate. But in case of stockpiles drying and wetting continuously add up to rate of spontaneous heating.

**Sulphur:** Initially it was believed that pyrites add up to spontaneous heating due to the presence of sulphur but later research work justified that coal absorbs oxygen in the absence of sulphides also which changed the belief.

**Ash/Mineral Matter:** Chemicals play a major role in accelerating or retarding spontaneous heating. Alkalis act as accelerators where as borated and calcium chlorides act as retardants. Also preheating improves spontaneous heating liability of coal samples. High ash content retards spontaneous heating process while silica detoriates the rate.

**Effect of extent of previous oxidation:** Fresh coals are relatively more reactive to oxygen rather than weathered coal which was justified from the fact that fresh coals had much lower ignition temperature than similar weathered coal.

**Physical properties:** Physical properties as porosity, thermal conductivity, hardness, specific heat can also do affect the rate of oxidation.

**Heating due to earth movement:** Heat evolved during crushing of rocks, goaf fall or pillar crushing may act as a cause of starting of self heating process.

**Bacteria:** Bacterias such as thiobaccillus ferro-oxidants and ferro-baccillus thio-oxidants play a major role during the auto oxidation process of coal. These bacteria's are inactive at -193°C and 560 °C.

**Pyrite contents:** The sulphides present in coal are pyrite, marcasite ,sparelite, galena, chalcopyrite and melnikovite-pyrite. Pyrites generally show catalytic effect as their oxidised product accelerates the rate of oxidation of organic compounds present in coal. The pyrite oxidation leads to formation of ferric ions which catalyzes the reaction. Also pyrite oxidation results in swelling which in turn causes breakage of the coal particles increasing the surface area for enhanced oxidation.

**Thermal conductivity:** In solid coals heat transfer is by conduction where as in broken coal heat transfer is by conduction and convection and it predominates at higher compactions. Convection gets enhanced at high temperature and low compactions, when moisture is evaporated and condensed. Moist coals with moisture around 5-7% are highly conductive.

### 3.3. THEORIES OF SPONTANEOUS COMBUSTION OF COAL

**3.3.1 Pyrite Theory**-There has been quite a few cases of heating due to oxidation of pyrites in pyrite mines. Heating can be availed in coal by presence of pyrite in considerable amount in

finely powdered and dispersed state being comprehended by moisture. The reaction of pyrites with oxygen in presence of moisture is exothermic and yields product of greater volume which leads to increase in surface area of the coal thus ensuring increased rate of oxidation.

$2Fe\ S_2 + 7 0_2 + 16 H_2O = 2\ H_2SO_4 + 2\ Fe\ S0_4.7\ H_2O + 316$ kcal

The oxidation of pyrite during weathering of coal seam may be represented by

$Fe\ S_2 + 15/4\ O_2 + 9/2\ H_2O = Fe\ O.OH + 2\ H_2SO_4$

Above equations suggest that oxygen and moisture are two prime weathering agents,which contribute to the pyrite alteration shown and it also leads to formation of sulphuric acid as by product of the alteration process. Presence of moisture doubles the reactivity rate of coal and presence of pyrite in dispersed form 10 folds the actual reaction rate.

Presence of pyrite in less of 5% showed negligible effect.

**3.3.2.Bacterial Theory-**Earlier bacteria was considered to add up to self- ignition of coal but further investigations clarified that bacteria's hardly had any influence on self heating of coal. The contribution of bacteria towards heating cannot be totally ruled out due to observance of spontaneous heating in haystacks due to bacterial action. Still, there is no justified fact to obey or discard the above concept.

**3.3.3.Phenol Theory-**Experimental research and investigations have justified that poly phenols and phenolic hydroxyls oxidize faster than many other organic groups. This theory is convincing as well as interesting as it drives a way in determining liability of coal to spontaneous heating.

**3.3.4 Humidity theory-**It stated that the quantity of heat required in removing water from coal is much high than the quantity of heat liberated by atmospheric oxidation of coal. The temperature of heating would definitely decrease if the evaporation is to be done at the cost of heating. But as a matter of fact water is one of the oxidation product formed during low temperature oxidation of coal along with co and co2.

**3.3.6 Coal-Oxygen Complex Theory**-The native radical sight is the point of initiation of oxidation of coal. The formation of peroxyl radical and hydro peroxides justifies the fact that during the formation mechanism oxygen and moisture are initially incorporated into an organic matrix. In fact these species may react, decompose, reform, alter to form a wide range of complex showing oxygen functionality in matrix or gaseous product form.

Kroger and Beier claimed that coal oxygen interaction occurs via formation of peroxy complex. The peroxy radical along with water lead to the formation of OH and OOH radicals. The above process consisted 3 stages:

**1.** The physical adsorption of oxygen which takes place at low temperatures and it requires low activation energy.

**2.** The Chemisorption step where motion of complex containing active form of oxygen called per oxygen occurred and it occurred between temperature range 70°C to 80°C.Much amount of heat is involved in this process.

**3.** Rapid chemical reaction resulting in decomposition of per-oxygen formed leading to release of CO,$CO_2$ and $H_2O$ and finally active combustion taking place.

# Chapter 4

# EXPERIMENTAL INVESTIGATION

Sample Collection and Preparation

Proximate Analysis

Determination of Calorific Value

Crossing Point Temperature

Flammability Temperature

Wet Oxidation Potential Analysis

# 4.0 EXPERIMENTAL INVESTIGATION

To carry out the experimental study, samples were collected from different collieries across India by channel sampling method. The intrinsic properties of the collected samples were determined by proximate analysis and bomb calorimetry experiment. Also in addition to that various Liability Index and susceptibility indices were determined by carrying out Crossing Point Temperature, Flammability Temperature and Wet Oxidation Potential analysis Experiments. Finally correlation coefficients were determined for dependence of susceptibility indices over intrinsic properties of coal.

## 4.1 Sample Collection and Preparation

Sampling is a method of collecting a small section of a large unit (i.e- in this case collecting a coal sample of a coal seam). For collection of sample for this project Channel Sampling was done at various mines. The seams were chosen of various collieries and a section of 10 cm width and 10 cm depth was marked and was drilled or picked out.

### 4.1.1Steps of channel sampling

Under written steps were followed during the process of Channel Sampling :

1. The face was prepared.

2. Channel was demarked through.

3. The Channel was cut through.

4. Sample was collected.

5. The channel was labelled.

6. Finally stored in plastic bags.

1. Preparation of the surface: The surface was thoroughly cleaned by using scrubbers or brushes in order to remove dirt, dust, oxidised part of coal being exposed, other soluble salts. Also at times the upper layer is chipped up to 10 cm thickness in order to expose a fresh face to continue with.

2. Demarcation of the channel: After cleaning the surface, a channel was demarked by drawing two parallel lines 12-15 cm apart by the use of chalk or paint.

3. Cutting the channel: Following it the channel was cut by the use of a hand pick (prospectors pick). Although in case of cutting channel in soft coal mines hand picks are used but in case of hard coal generally a light weight air operated drill machine is used. In case of underground mines drill machines are used to cut channels in case where more no of samples are to be collected in a single shift.

4. Collection the sample: A sheet of canvas was spread on the floor in order to collect the coal chips as they fall through.

5. Labelling the sample: After collecting the coal sample the canvas bag was wrapped through and was tagged .Then the tagged sac was brought out of the mine.

The collected samples from different coalfields were brought to the laboratory. The collected samples were then crushed to smaller pieces. Further Coning and quartering procedure was done in order to get a representative sample of the entire coal seam. Finally the samples were grounded and screened (sieving) to a size of - 212 (micron). Then the samples were stored in sealed packets for further analysis process.

8 samples were collected by the following procedure from different colliery belonging to NECL, MCL, BCCL, SECL, SCCL, and WCL.

## 4.2. PROXIMATE ANALYSIS

Proximate analysis id primarily done to determine the intrinsic properties of coal such as:

1. Moisture Content

2. Ash Content

3. Volatile Matter Content

4. Fixed Carbon

For determination of Proximate Analysis the method specified by IS(Indian Standard) 1350(Part-1)-1969 was followed.

### 4.2.1 Determination of Moisture Content

Coal, due to its nature, origin and occurrence, is always associated with some amount of moisture, which is both physically and chemically bound. It is differentiated between external and inherent moisture. When a wet coal is exposed to atmosphere, the external moisture evaporates, but the apparently dry coal still contains some moisture, which can be removed only on heating above 100°C. External moisture is also called accidental or free moisture, where as inherent moisture is termed as equilibrium or air-dried or hygroscopic moisture. The quantity of external moisture depends mainly on the mode of occurrence and handling of coal, but the air-dried moisture is related to the inherent hygroscopic nature of the coal.

**Experimental Procedure -**1g of finely powdered air-dried coal sample (-212μ) was weighed in a silica crucible and was placed inside an electric hot air oven (Fig no 4.2.1) maintained at 108°C. The crucible with the coal sample was kept in the oven for 1.5 hours and was then taken out with a pair of tongues, cooled in a desiccator for about 15 minutes and then weighed. The

loss in weight was reported as moisture (on percentage basis). The calculation was done as per the following.

$$\% \text{ Moisture} = \frac{Y - Z}{Y - X} * 100$$

Where X = weight of empty crucible, g

Y = weight of crucible + coal sample before heating, g

Z = weight of crucible + coal sample after heating, g

Y - X = weight of coal sample, g

Y- Z = weight of moisture, g


**Fig 4.2.1 Oven for Moisture Content Determination**

**Fig no 4.2.2 Muffle Furnace for Ash Content & Volatile Matter Determination**

### 4.2.2 Determination of Volatile Matter Content

The loss of mass, corrected for moisture, which results when coal is heated in specified equipment under prescribed conditions, is referred to as volatile matter. The matter lost is composed of materials that form upon the thermal decomposition of the various components of coal. Some of the constituents of coal volatile matter are hydrogen, carbon monoxide, methane, other hydrocarbons, tar vapours, ammonia, some organic sulphur, oxygen containing compounds and some incombustible gases, such as carbon dioxide and water vapour.

**Experimental Procedure**

For the determination of volatile matter a special volatile matter silica crucible (38mm height, 25mm external diameter and 22mm internal diameter) was used. The empty volatile matter crucible was weighed. Approximately 1g of coal sample (-212 size) was weighed in the volatile matter crucible and it was placed inside a muffle furnace maintained at 925°C with the lid

covering the crucible. The heating was carried I the muffle furnace (Fig no. 4.2.2) out exactly for seven minutes, after which the crucible was removed, cooled in air, then in a desiccator and weighed again. The calculation was done as per the following.

$$\% \text{ Volatile Matter} = \frac{Y - Z}{Y - X} * 100 - M$$

Where X = weight of empty crucible, g

Y = weight of crucible + coal sample before heating, g

Z = weight of crucible + coal sample after heating, g

Y -X = weight of coal sample, g

Y- Z = weight of volatile matter + moisture, g

### 4.2.3 Determination of Ash Content

Coal ash is the residue remaining after the combustion of coal under specified conditions. It does not occur as such in the coal, but is formed as the result of chemical changes that take place in the mineral matter during the combustion process. Ash and mineral matter of coal are therefore not identical.

There are two types of ash forming materials in coal: extraneous and inherent mineral matters. The extraneous mineral matter consists of materials such as calcium, magnesium and ferrous carbonates, pyrite, marcasite, clays, shales, sand and gypsum. The extraneous mineral matter owes its origin to i) the substances which got associated with the decaying vegetable material during its conversion to coal, which is difficult to remove by mechanical methods, and ii) rocks and dirt getting mixed up during mining and handling of coal. Inherent mineral matter represents the inorganic elements combined with organic components of coal. The origin of such materials is probably the plant materials from which the coal was formed.

Ash from inherent mineral matter is insignificant as far as the total quantity of ash is concerned. But Indian coals suffer from the major disadvantage, that the mineral matter content is not only high, but of intimately associated type, due to its drift origin.

**Experimental Procedure**

The empty crucible was cleaned by heating in a muffle furnace for one hour at 800°C so that other mineral matter if presents get burnt. It was taken out, cooled to room temperature and the weight is taken. Approximately 1gm of coal sample was weighed in the crucible and placed in a muffle furnace at 450°C for 30 minutes and the temperature of the furnace was raised to 850°C for 1hour. The crucible was taken out and placed in a desiccator and weighed.

$$\% \text{ Ash} = \frac{Z - X}{Y - X} * 100$$

Where X = weight of empty crucible in grams

Y = weight of coal sample + crucible in grams (Before heating)

Z = weight of coal sample + crucible in grams (After heating)

Y - X = weight of coal sample, g

Z - X = weight of ash, g

**4.2.4 Determination of Fixed Carbon (FC)**

Fixed carbon (FC) is by definition, the mathematical remaining after the determination of moisture, volatile matter and ash. It is, in fact a measure of the solid combustible material in coal after the expulsion of volatile matter. Fixed carbon plus ash represent the approximate yield of coke from coal. The fixed carbon value is determined by subtracting from 100 the resultant summation of moisture, volatile matter and ash, with all percentage on the same moisture reference base.

FC= 100-(VM+M+A)

The moisture (M), volatile matter (VM), Ash and Fixed carbon content of coal determined by following the above procedure is presented in Table 4.1.

Table no 4.2.1 Volatile Matter(VM),Ash(A),Moisture(M) and Fixed Carbon(FC) of coal

| Sl no. | Sample | Volatile Matter(VM%) | Moisture(M%) | Ash(A%) | Fixed Carbon(FC%) |
|---|---|---|---|---|---|
| 1. | MCL1 | 32.015 | 13.575 | 11.3 | 43.11 |
| 2. | NECL1 | 39.2 | 3.41 | 2.005 | 55.385 |
| 3. | SECL1 | 29.115 | 10.215 | 26.01 | 34.66 |
| 4. | WCL1 | 31.56 | 12.32 | 11.915 | 44.205 |
| 5. | SCCL1 | 27.795 | 6.95 | 25.535 | 39.72 |
| 6. | BCCL1 | 17.23 | 1.3 | 26.845 | 54.625 |
| 7. | SECL2 | 29.905 | 6.75 | 23.46 | 39.885 |
| 8. | MCL2 | 24.94 | 6.955 | 33.83 | 34.275 |

### 4.3. Determination of Calorific Value

#### 4.3.1 Bomb Calorimetry

The energy value of a coal sample refers to the amount of potential energy stored in coal which can be effectively used as actual heating ability. Depending upon the Gross Calorific Value (GCV) coals are classified into different grades. And to measure the same Digital Bomb calorimeter was used.

**Calorific Value**

The energy value of coal, or the fuel content, is the amount of potential energy in coal that can be converted into actual heating ability. The process of measuring the heat of chemical reactions or physical changes as well as heat capacity is called calorimetry and the object used for measuring the energy value is called as calorimeter. The value differs with grades of coal or materials as different materials of different grades produces differing amounts of heat for a given mass.

A bomb calorimeter consists of a small cup to contain the sample, oxygen, a stainless steel bomb, water, a stirrer, a thermometer, the insulating container (to prevent heat flow from the calorimeter to the surroundings) and ignition circuit connected to the bomb. By using stainless steel for the bomb, the reaction will occur with no volume change observed. `It is a type of constant-volume calorimeter used in measuring the heat of combustion of a particular reaction. They withstand a large pressure within the calorimeter as the reaction is being measured. Electrical energy is used to ignite the fuel; as the fuel is burning, it will heat up the surrounding air, which expands and escapes through a tube that leads the air out of the

calorimeter. When the air is escaping through the copper tube it will also heat up the water outside the tube. The temperature of the water allows for calculating calorie content of the fuel.

**Experimental Procedure**

The Calorific value of the coal in digital bomb calorimeter can be calculated by five steps:

Step – 1 (Initials)

About 1gm of sample is taken in a crucible. The desired weight can be done carried out manually or entered digitally. Two liters of distilled water is filled in the outer jacket..5 to 10 ml of water is placed inside the bomb.

Step -2 (Connection of Igniting Wires)

The sample (powder form) is placed in the crucible in the bomb by the help of tripod stand. The two electrodes are connected by nichrome wire touching the coal sample. The bomb is now tightened by the lid.

Step – 3 Filling of Oxygen

After tightening the lid of the bomb, oxygen is to be filled into it. It takes 1 minute to fill desired amount oxygen in the bomb. It is filled into the bomb by connecting it into the gas pipe socket of the bomb head and oxygen cock to the cylinder. The cock is then unscrewed to fill the oxygen of 420 psi (400 – 450).

Step -4 Run of program

The bomb is placed inside the outer jacket which gets immersed in distilled water. The electrodes are fitted to the bomb before the cover of the bomb is to be shut down. Sufficient care is to be

taken to avoid the contact of stirrer to the bomb. The device is now ready to run which on running will give us the result of calorific value and temperature rise of coal.

Step -5 Reaction

The whole bomb is now pressurized with excess pure oxygen (typically at 30atm) which contains a weighed mass of a sample (1-1.5 g) and a small fixed amount of water (to saturate the internal atmosphere, thus ensuring that all water produced is liquid, and removing the need to include enthalpy of vaporization in calculations), is submerged under a known volume of water (2 l) before the charge is electrically ignited. The bomb, with the known mass of the sample and oxygen, form a closed system does not allows gases to escape during the reaction. The weighted reactant put inside the steel container is then ignited. Energy is released by the combustion and heat flow from this crosses the stainless steel wall, thus raising the temperature of the steel bomb, its contents, and the surrounding water jacket. The temperature change in the water is then accurately measured with a thermometer. This reading, along with a bomb factor (which is dependent on the heat capacity of the metal bomb parts), is used to calculate the energy given out by the sample burn. A small correction is made to account for the electrical energy input, the burning fuse, and acid production (by titration of the residual liquid). After the temperature rise has been measured, the excess pressure in the bomb is released.


Fig no 4.3.1 Experimental setup of Digital Bomb Calorimeter and auto filling of Oxygen in Bomb.

Table no 4.3.1 Ultimate Heating Value (UHV) of coal and its Grade

| Sl no. | Sample | Ultimate Heat Value(Kcal/Kg) | Grade |
|---|---|---|---|
| **1.** | MCL1 | 5467.25 | C |
| **2.** | NECL1 | 8152.73 | A |
| **3.** | SECL1 | 3900.95 | E |
| **4.** | WCL1 | 5555.57 | C |
| **5.** | SCCL1 | 4417.07 | D |
| **6.** | BCCL1 | 5015.99 | C |
| **7.** | SECL2 | 4731.02 | D |
| **8.** | MCL2 | 3271.67 | F |

Table no 4.3.2 Gross Calorific Value(GCV) of coal and its grade

| Sl no. | Sample | Gross Calorific Value(Kcal/Kg) | Grade |
|---|---|---|---|
| **1.** | MCL1 | 5574.3665 | D |
| **2.** | NECL1 | 7167.3499 | A |
| **3.** | SECL1 | 3946.8717 | F |
| **4.** | WCL1 | 6122.5100 | B |
| **5.** | SCCL1 | 5071.3672 | E |
| **6.** | BCCL1 | 6049.2439 | B |
| **7.** | SECL2 | 5510.1490 | D |
| **8.** | MCL2 | 4574.2311 | E |

## 4.4.Crossing Point Temperature

It refers to the minimum temperature at which the coal temperature coincides with that of the bath temperature. This method is primarily used in India for determination of liability of coal samples towards spontaneous heating.

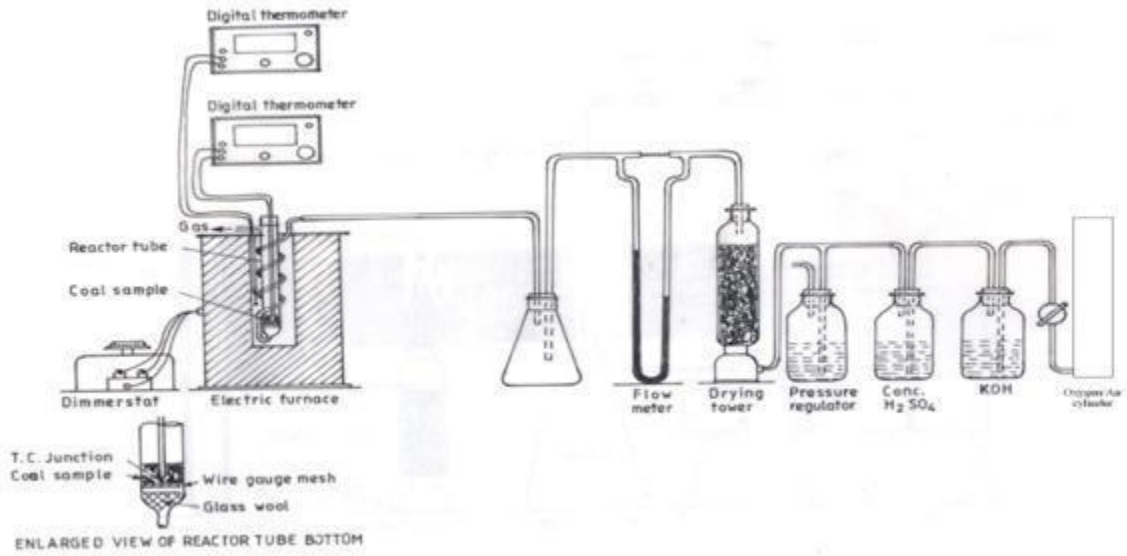



Fig no 4.4.1 Schematic layout of Crossing Point Temperature Apparatus

**Experimental procedure**

In this method initially coal sample is prepared of size -212 micron. Next to that 4 gram of coal sample was taken and was placed inside a helical test tube over some glass wool initially placed inside the tube. Then the helical glass tube was place inside the furnace and one end of the reaction tube was connected to a valve which supplies constant oxygen flow to the reaction tube at a rate of 80ml/min.Following it the reaction tube was placed inside the air bath furnace and a constant heating rate of 1 degree celcius rise per min was maintained via a rheostat. Continuous reading were noted of the coal and the bath temperature at interval of 3-4 minutes and finally the

experiment is stopped when the coal temperature crosses the bath temperature. Same procedure was applied for all the 8 samples and the liability to spontaneous heating and the risk rating was determined using the table 4.4.1,4.4.2.

(Mahadevan et al,.,1985) proposed a new Liability Index or MR Index after analysing several CPT curves. He divided the heating curve into 3 stages.

The 1st stage was considered upto the point of inflexion( i.e upto a point at which the rate of heating rapidly increased called the inflextion point).

The 2nd stage started from the inflexion point and ended at the Crossing Point Temperature.

The 3rd stage was considered to start from the crossing point temperature and ended at active combustion.

$$\text{Liability Index} = \frac{\text{Heating rate at CPT* Time taken to reach the Inflexion point * 10)}}{\text{(Time taken to reach the CPT* Average Heating Rate between the Inflexion point and Crossing point)}}$$

The risk rating with respect to the liability index :

Table no 4.4.1 Liability Index (Mahadevan et al.,1985)

| Liability Index | Risk Rating |
|---|---|
| **0-10** | low |
| **10-20** | Medium |
| **>20** | High |

Table no 4.4.2. Classification of CPT(Mahadevan et al.,1985)

| CPT (°C) | Risk Rating |
|---|---|
| **120-140** | Highly susceptible |
| **140-160** | Moderately susceptible |
| **>160** | Poorly susceptible |

WITS-EHAC Index(Uludag,2007) of self- heating liability of coal is calculated from the following formula:

Area of the triangle= 0.5* Stage 2 slope *——————*1000

Table no 4.4.3 Crossing Point Temperature, Liability Index,WITS-EHAS and its Risk Rating.

| Sl no. | Sample | CPT (°C) | Risk Rating | Liability Index | Risk Rating | WITS-EHAC |
|---|---|---|---|---|---|---|
| **1.** | MCL1 | 159 | Moderately susceptible | 18.39 | Medium | 4.77 |
| **2.** | NECL1 | 193 | Poorly susceptible | 8.47 | Low | 3.435 |
| **3.** | SECL1 | 161 | Poorly susceptible | 6.18 | Low | 3.86 |
| **4.** | WCL1 | 155 | Moderately susceptible | 11.27 | Medium | 3.87 |
| **5.** | SCCL1 | 126 | Highly susceptible | 10.09 | Medium | 4.55 |
| **6.** | BCCL1 | 222 | Poorly susceptible | 7.06 | Low | 2.34 |
| **7.** | SECL1 | 158 | Moderately susceptible | 15.64 | Medium | 4.101 |
| **8.** | MCL2 | 160 | Moderately susceptible | 14.17 | Medium | 4.71 |

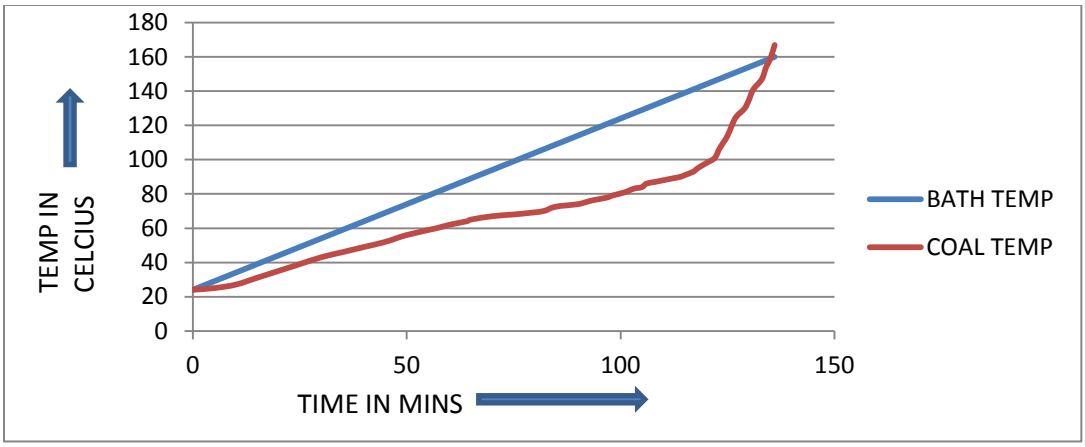



Fig no 4.4.2 CPT Curve for Sample MCL1

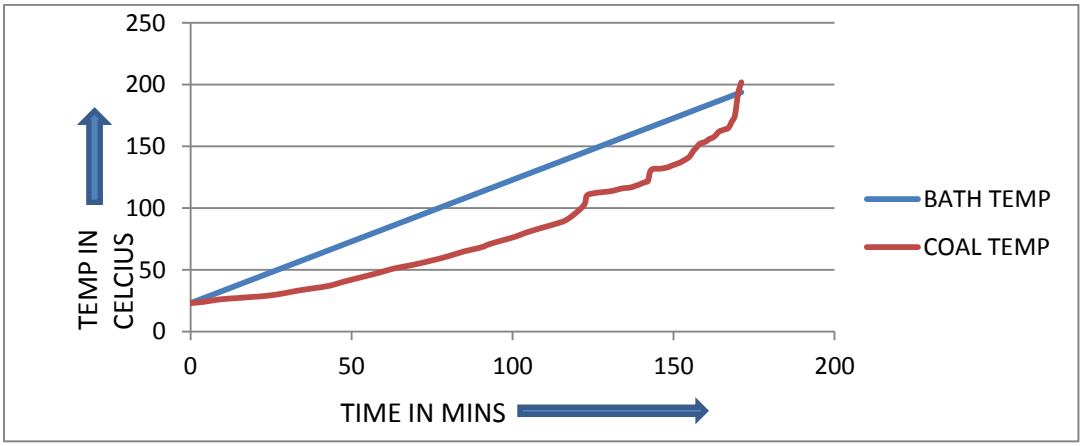



Fig no 4.4.3 CPT Curve for Sample NECL1

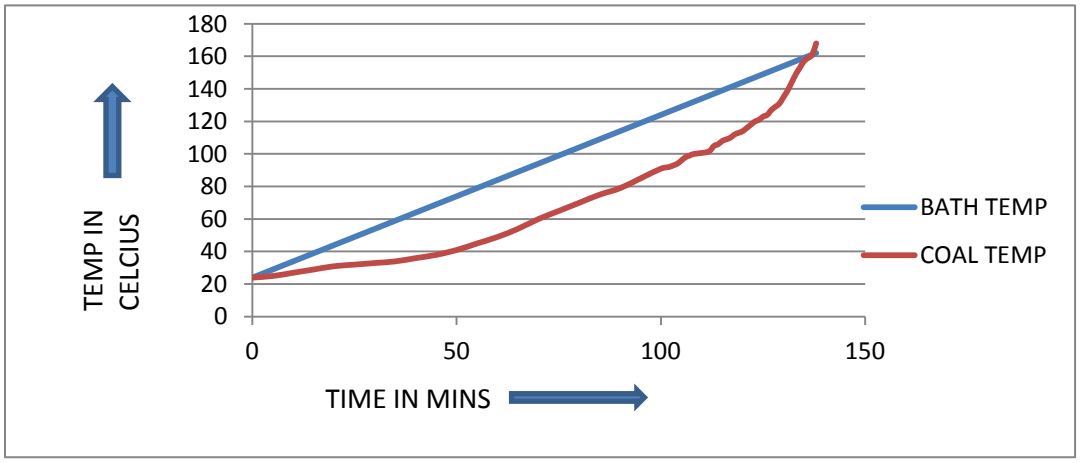



Fig no 4.4.4 CPT Curve for Sample SECL1

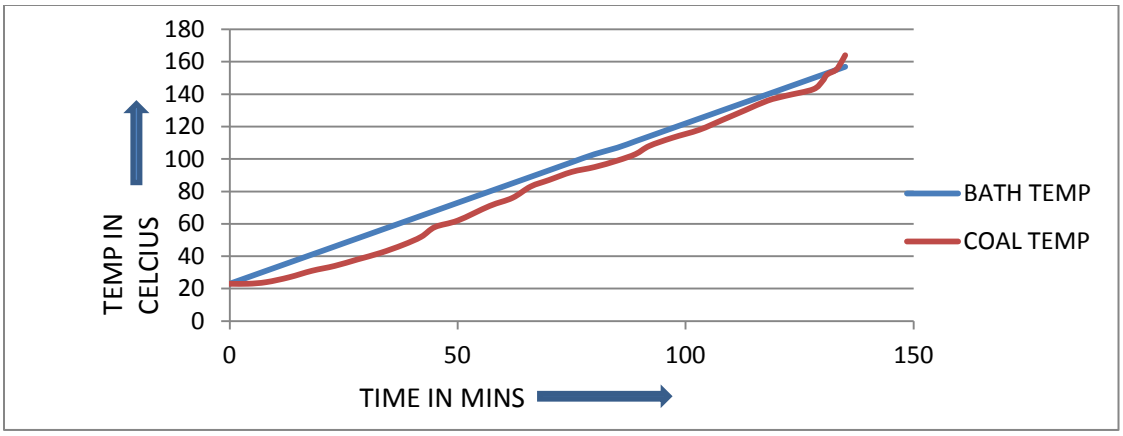



Fig no 4.4.5 CPT Curve for Sample WCL1

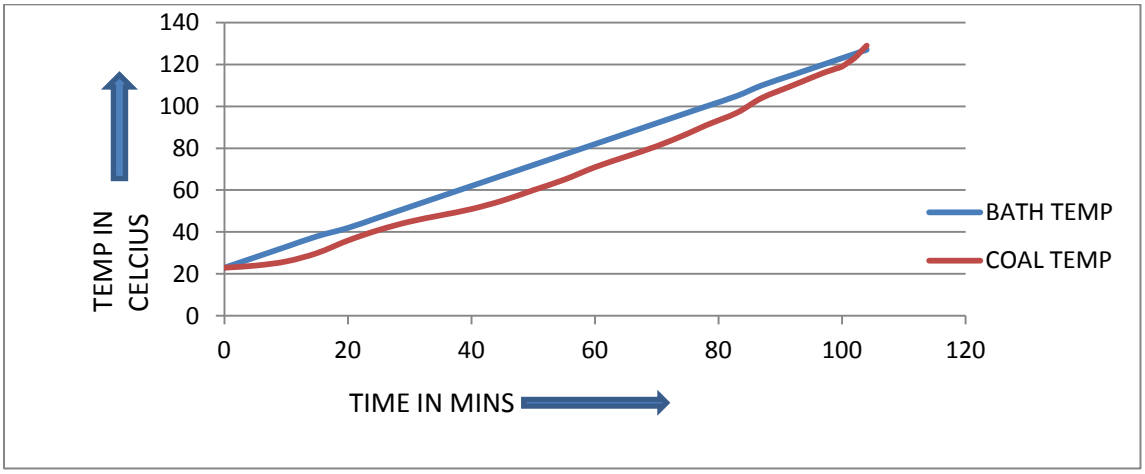



Fig no 4.4.6 CPT Curve for Sample SCCL1

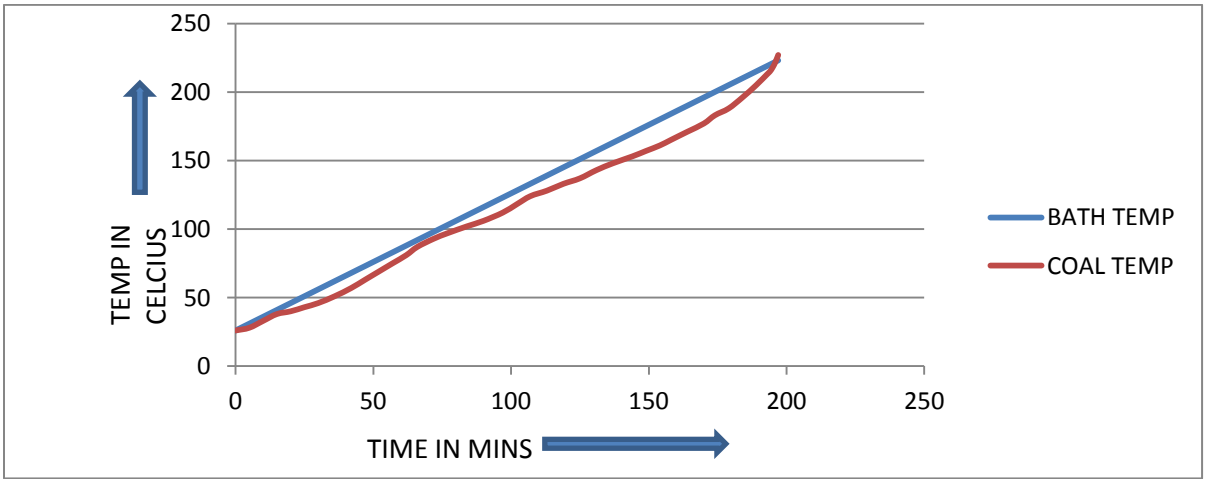



Fig no 4.4.7CPT Curve for Sample BCCL1

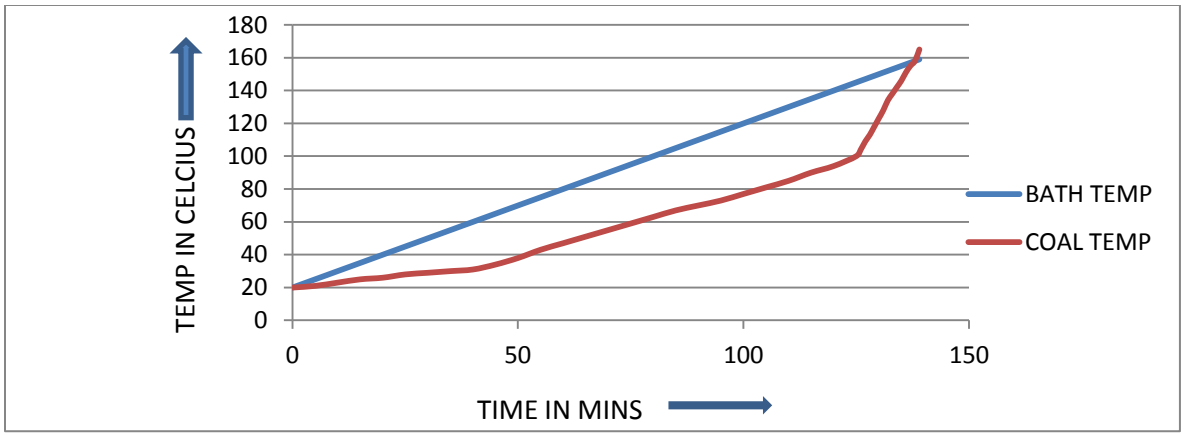



Fig no 4.4.8 CPT Curve for Sample SECL2

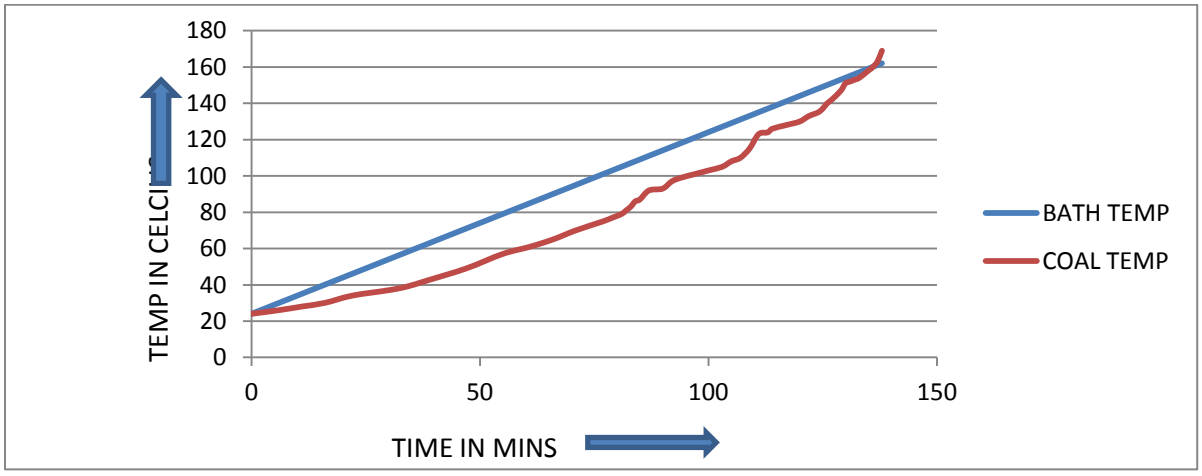



Fig no 4.4.9 CPT Curve for Sample MCL2

### 4.5.Flammability Temperature(Nimaje et al., 2010)

It basically refers to the minimum temperature at which coal ignites. Here the concept is based on the ideology that flammability temperature of a coal sample decreases with increasing oxidation of coal and this concept of difference between the ignition temperature of coal after and before oxidation can be used as a tool to determine the liability of coal samples to spontaneous combustion.It is used to determine the efficiency of coal dusting . The experimental

set up consists of a vertical tubular furnace of internal diameter 50 mm, length 300 mm which is open at both ends having a a dust dispersing unit along a solenoid valve and a reservoir for air.It also consists of a mercury manometer, a drying tower and an aspirator bulb. Coal dust sample is kept in the helical dust disperser. Air at an pressure of 50 mm of Hg from the reservoir is made to pass through the disperser in order to disperse the powdered coal forming a uniform air-dust mixture within the furnace. The minimum temperature at which this mixture catches fire, which is indicated by the appearance of flame coming out of the bottom of the tubular furnace is known as the flammability temperature of the coal dust.

**Experimental Procedure:**

 200 mg sample of coal having mesh size -72 micron (-200 mesh BSS) was placed in a helical tube.

 The aspirator bulb was squeezed continuously to make the mercury column difference maintained at a pressure of 80 mm.

 After switching on the solenoid valve, at the desired temperature of furnace, the air passes at a very fast rate and carries away the coal dust along with it to show signs of flame, smoke or spark.

 If flame appears then in order to determine the exact temperature experiment is carried out in lower temperature range or else we move on to high temperature range. But in all it's a hit and trial method of identifying the exact Flammability Temperature. Precaution should be taken to pre dry the circulated air in order to avoid error due to humidity.

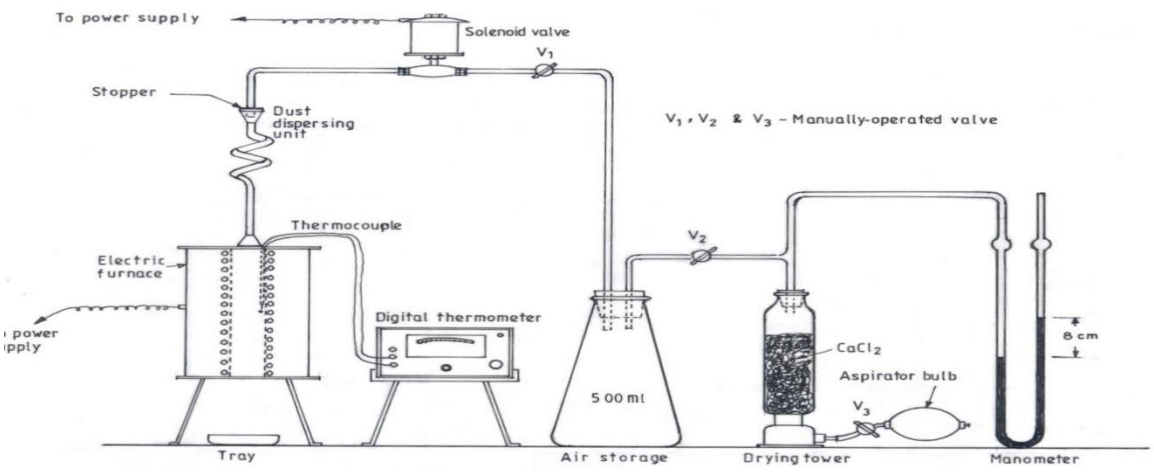



Fig no 4.5.1 Schematic Layout of Flammability Apparatus

Table no 4.5.1 Flammability Temperature of the Coal Samples

| Sl no. | Sample | Flammability Temperature(°C) |
|---|---|---|
| **1.** | MCL1 | 505 |
| **2.** | NECL1 | 500 |
| **3.** | SECL1 | 540 |
| **4.** | WCL1 | 515 |
| **5.** | SCCL1 | 415 |
| **6.** | BCCL1 | 450 |
| **7.** | SECL2 | 545 |
| **8.** | MCL2 | 530 |

**4.6 Wet Oxidation Potential Analysis:**

Coal molecules constitutes two part:

1.The condensed aromatic structure which in totally resistant tooxidation.

2. The hydro-aromatic structure or the aliphatic(open chain) part that are highly prone to oxidation.

Basically presence of hydroxyl groups in the aromatic part adds up to the reactivity rate of the coal structure and oxidises it faster. Above mentioned reason is one of the prime cause of fast oxidation of low rank coals. In addition to that also low rank coals have lower degree of condensation of aromatic structure in it. On oxidation low rank coals produce huge amount of aliphatic acids mainly formed from base aliphatic presence in low rank coals. But higher rank coals have have structure similar to that of graphite which helps it in formation of aromatics rather than aliphatics. Hence ,lower the potential difference lower is the liability of coal towards spontaneous heating.

**Experimental Procedure**

Initially a solution of 100ml mixture was formed by mixing 0.1 N solution of potassium permanganate and 1N potassium hydroxide. Then this solution was placed inside the beaker and the magnetic stirrer is allowed to stir smoothly the solution. Then 0.5 gram of coal sample of 212 micron size was weighed and kept aside. Next to that e carbon and calomel electrodes were dropped into the solution and the millivoltmeter was turned on. After that the weighed coal sample was put inside the solution and the resultant coal oxidation suspension was continuously stirred by the magnetic stirrer and the potential difference(EMF) between the carbon and calomel

electrode was noted down within every 1 minute upto 30 minutes until the potential difference value becomes constant. The higher the Potential Difference ,the higher the liability towards spontaneous heating.

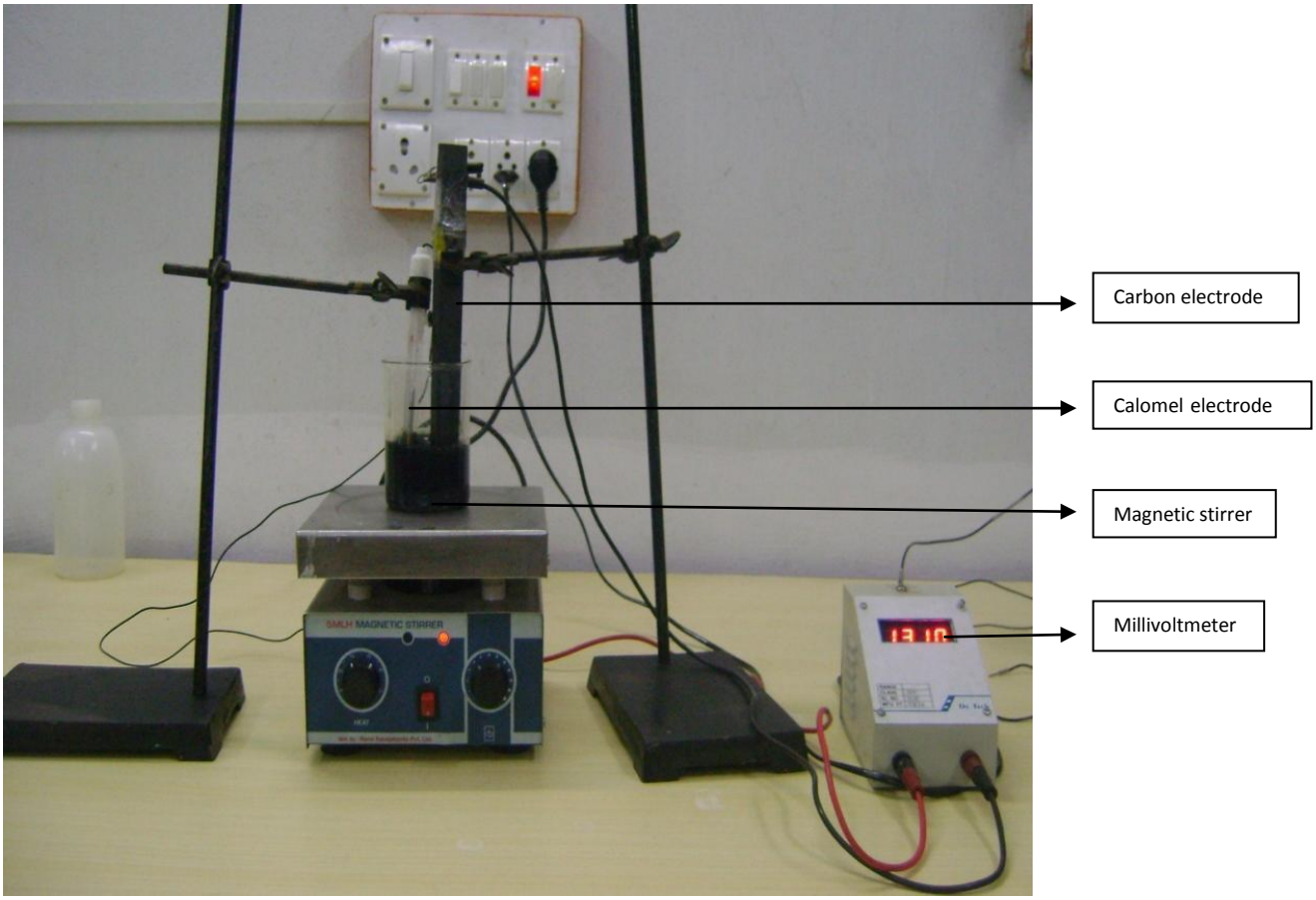



Fig no 4.6.1 Experimental set up of Wet Oxidation Potential Apparatus

Table no 4.6.1 –Wet Oxidation Potential Difference of the coal samples

| Sl no. | Sample | Wet Oxidation Potential Difference(mV) |
|---|---|---|
| **1.** | MCL1 | 65.2 |
| **2.** | NECL1 | 22.4 |
| **3.** | SECL1 | 43.4 |
| **4.** | WCL1 | 48 |
| **5.** | SCCL1 | 73 |
| **6.** | BCCL1 | 17.4 |
| **7.** | SECL2 | 36.3 |
| **8.** | MCL2 | 56.3 |

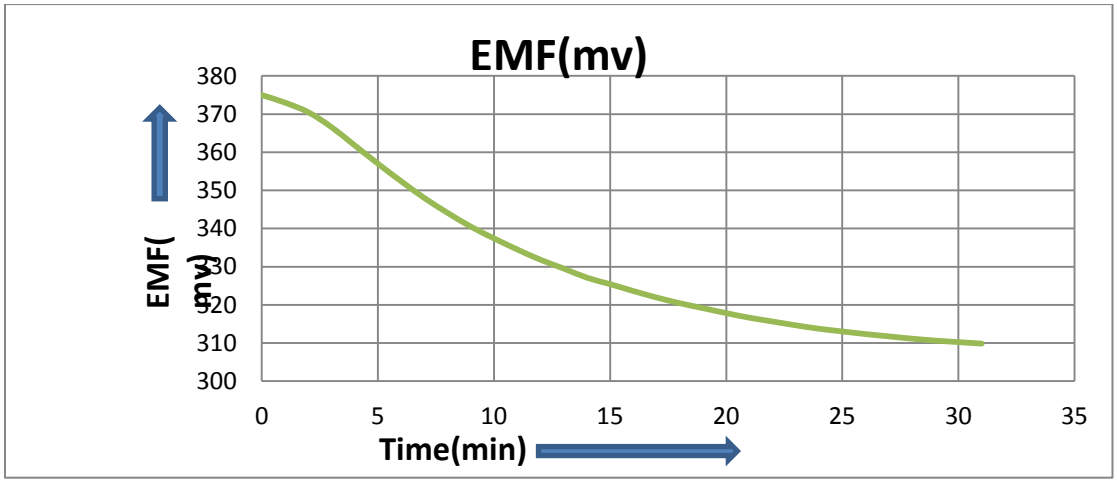



Fig no 4.6.2 Wet Oxidation Curve for Sample MCL1

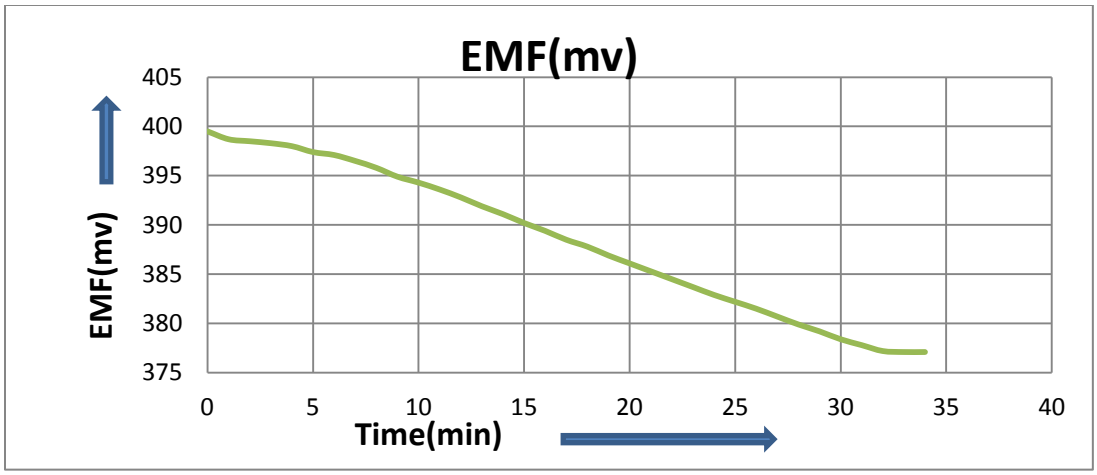



Fig no 4.6.3 Wet Oxidation Curve for Sample NECL1

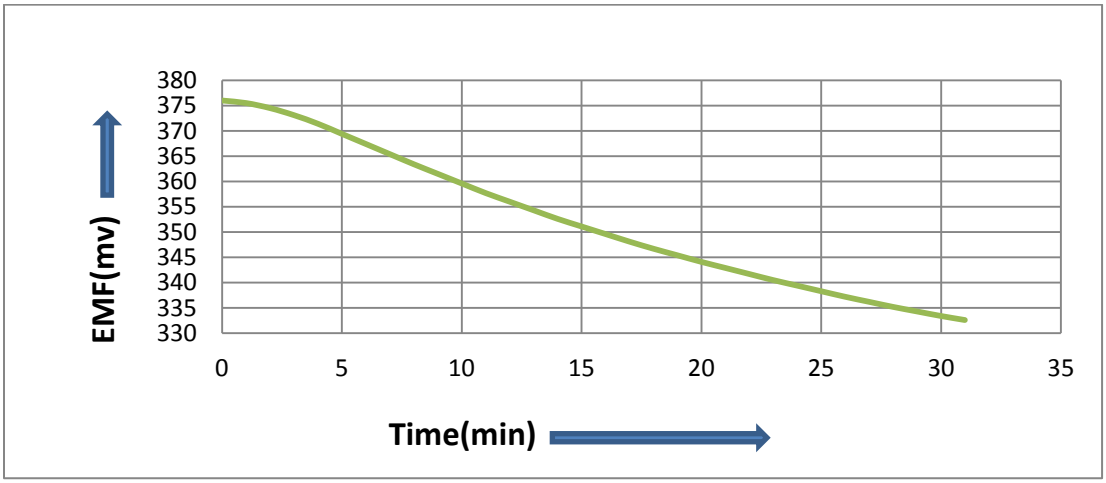



Fig no.4.6.4 Wet Oxidation Curve for Sample SECL1

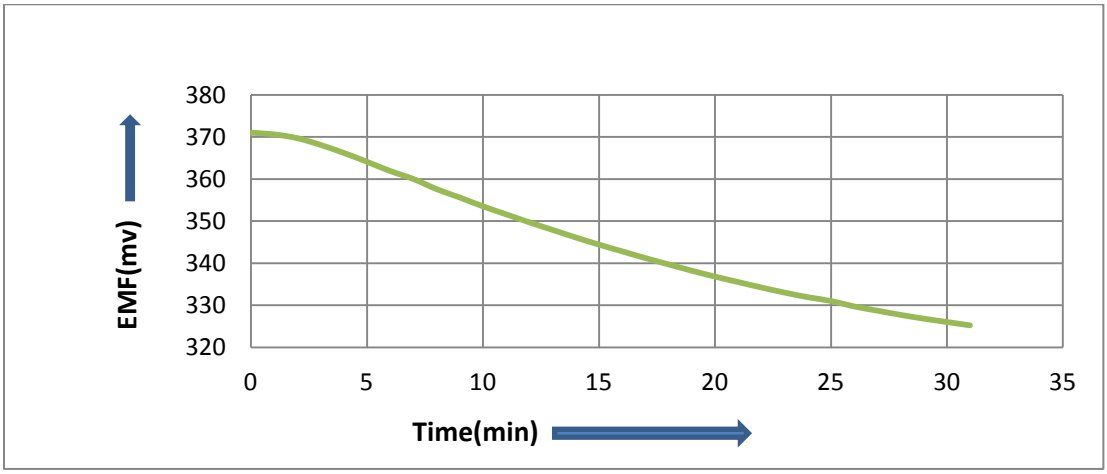



Fig no.4.6.5 Wet Oxidation Curve for Sample WCL1

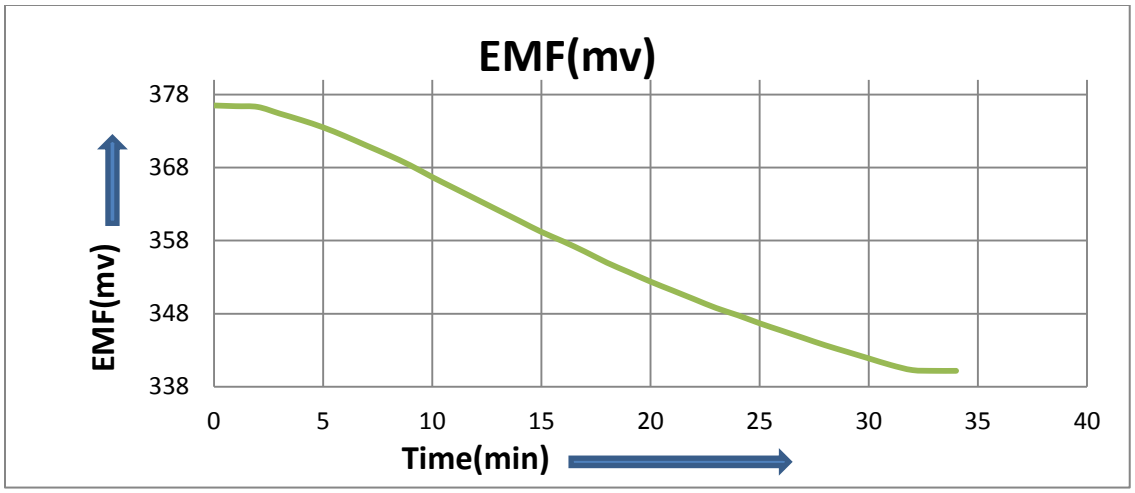



Fig no.4.6.6 Wet Oxidation Curve for Sample SCCL1

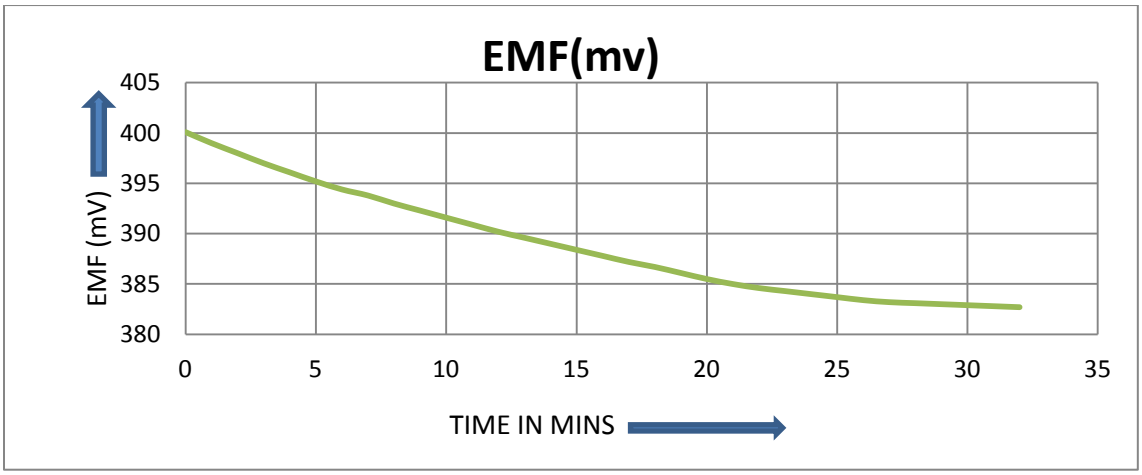



Fig no 4.6.7 Wet Oxidation Curve for Sample BCCL1

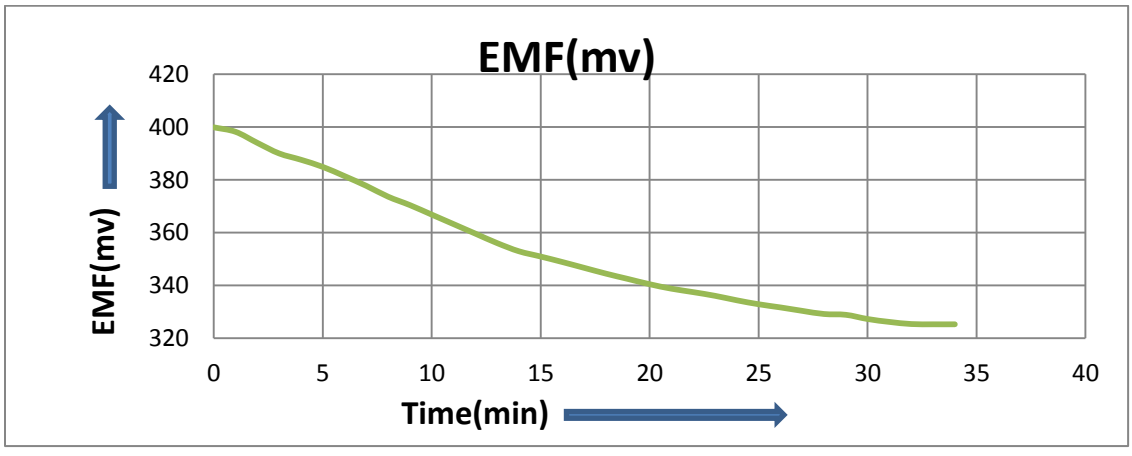



Fig no . 4.6.8 Wet Oxidation Curve for Sample SECL2

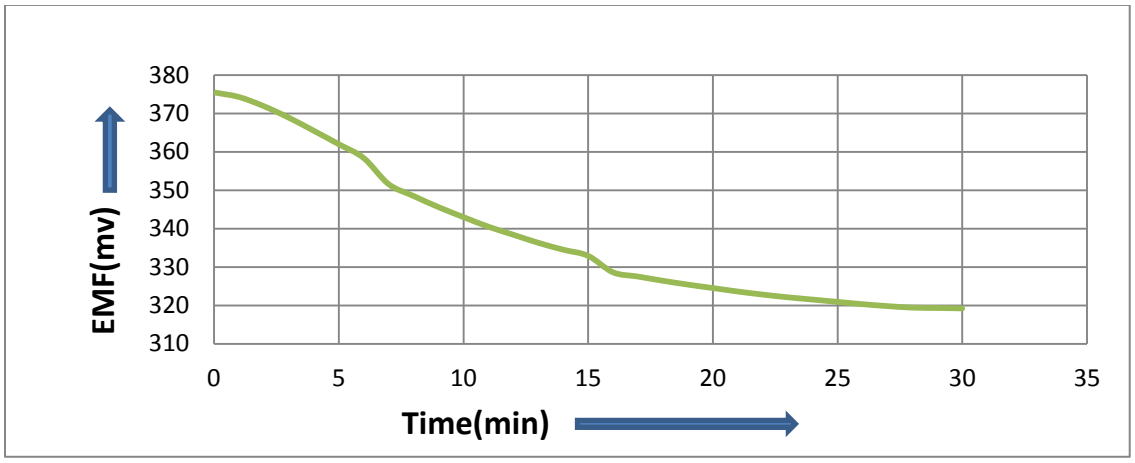



Fig no 4.6.9 Wet Oxidation Curve for Sample MCL2

# Chapter 5

# DISCUSSION AND CONCLUSION

Discussion

Conclusion

## 5.1 Discussion

1.The moisture content of the various coal samples varied from 1.3% to 13.575% with MCL1 being the highly moist coal and BCCL1,the least moisture content. High moisture content in MCL1 is because the seam is watery in nature which justifies field observation.

2.High moisture content and low fixed carbon in SECL1 conveys the coal seam is highly prone to spontaneous heating.

3.Low fixed carbon content along with high volatile matter content in SCCL1 shows the coal seam is highly susceptible to spontaneous heating.

4.Low moisture content and high fixed carbon content in BCCL1 & NECL1 conveys these seam do not pose any spontaneous heating problem.In fact they are poorly susceptible to spontaneous heating.

5.The average values of moisture,relatively high value of volatile matter in case of MCL2,SECL2,WCL,MCL1 shows they are moderately to poorly susceptible to spontaneous heating.

6.High Gross Calorific Value of the samples NECL1,BCCL1 shows that they are good rank coal and hence very less susceptible to spontaneous heating.

7.The highest Wet Oxidation Potential Difference in case of SCCL1 shows that it is highly prone to rapid oxidation resulting in highly susceptible to spontaneous heating problems.

8.Averagely high value of Wet Oxidation Potential Difference in case of MCL1,MCL2 and WCL1 suggests these respective coal seams are moderately susceptible to spontaneous heating.

9.Low values of Wet Oxidation Potential Difference in case of BCCL1,NECL1 claims that these seams are less susceptible to spontaneous heating.

10.Lowest Flammability temperature of SCCL1 shows that it is highly prone to spontaneous heating.

11.High Crossing Point Temperature of BCCL1 & NECL1 shows that they are poorly susceptible to spontaneous heating.

12.SCCL1 has the lowest Crossing point temperature value which claims that it is highly susceptible to spontaneous heating and field investigation also supports the argument.

13.Relatively average values of Crossing point temperature of samples from MCL1,WCL1,SECL2,MCL2 shows that they are moderately susceptible to spontaneous heating.

Above discussion shows that most of the Indian coals are moderately to poorly susceptible to spontaneous heating where as few seams are totally free of spontaneous heating related issues.

Correlation studies were carried out between various susceptibility indices and the coal properties as obtained from proximate analysis. The susceptibility parameters were taken as dependent variables where as the the coal properties were taken as independent variables and the correlation coefficients were found out. Also the trendline curves were modelled to show the dependence of susceptibility indices on the various coal intrinsic properties.

Table no.5.1.1 Correlation coefficients between various susceptibility parameters and the proximate analysis values.

| Sl no. | Dependent variable | Independent variable | Correlation coefficient(r) |
|---|---|---|---|
| **1.** | CPT | Moisture | -0.63628 |
| **2.** | CPT | Volatile matter | -0.29151 |
| **3.** | CPT | Ash Content | -0.14875 |
| **4.** | Flammability temperature | Moisture | 0.3869 |
| **5.** | Flammability temperature | Volatile Matter | 0.3328 |
| **6.** | Flammability temperature | Ash Content | -0.0494 |
| **7.** | Wet Oxidation Potential Difference | Moisture | 0.662 |
| **8.** | Wet Oxidation Potential Difference | Volatile Matter | 0.0874 |
| **9.** | Wet Oxidation Potential Difference | Ash Content | 0.199 |
| **10.** | WITS-EHAC | Moisture | 0.66 |

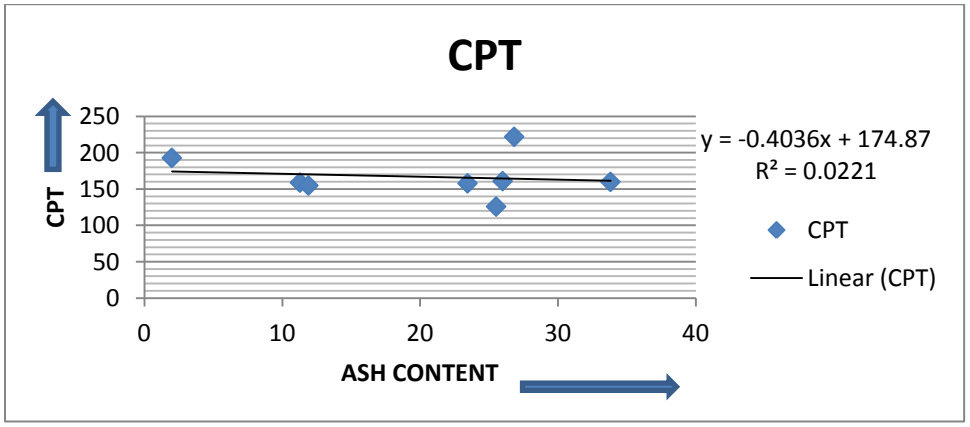



Fig no 5.1.1 variation of CPT vs Ash Content

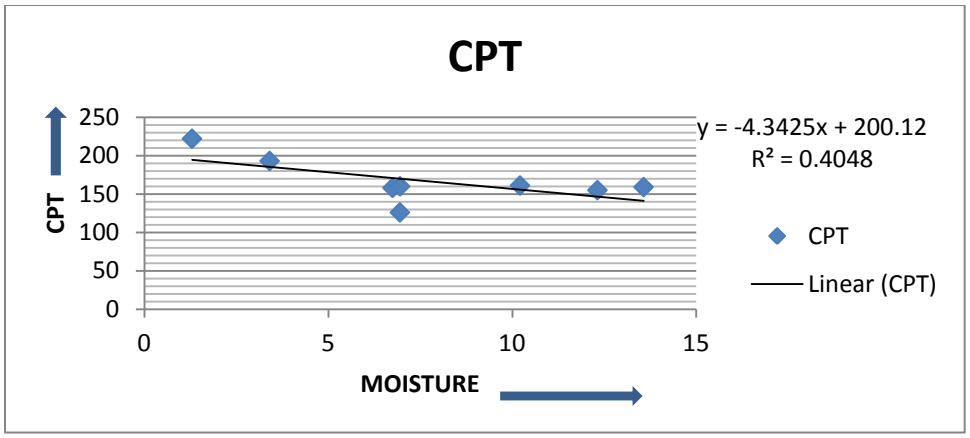



Fig no 5.1.2 variation of CPT vs Moisture

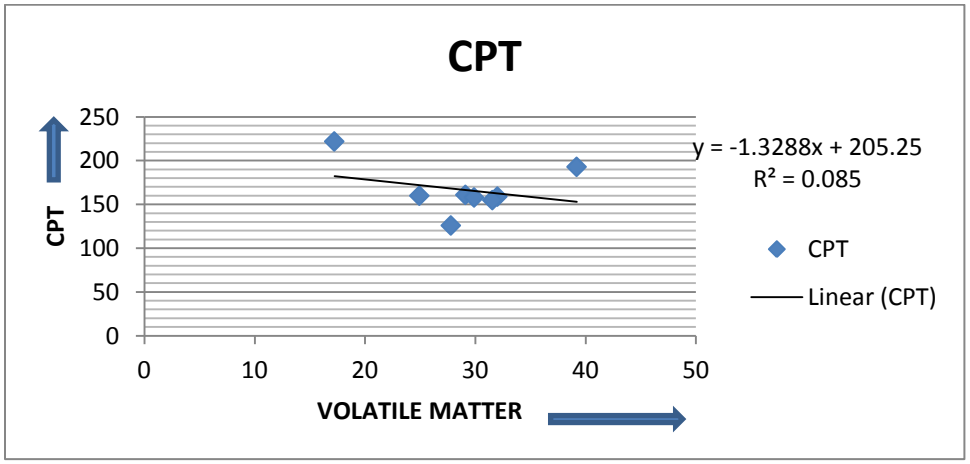



Fig no 5.1.3 Variation of CPT vs Volatile Matter

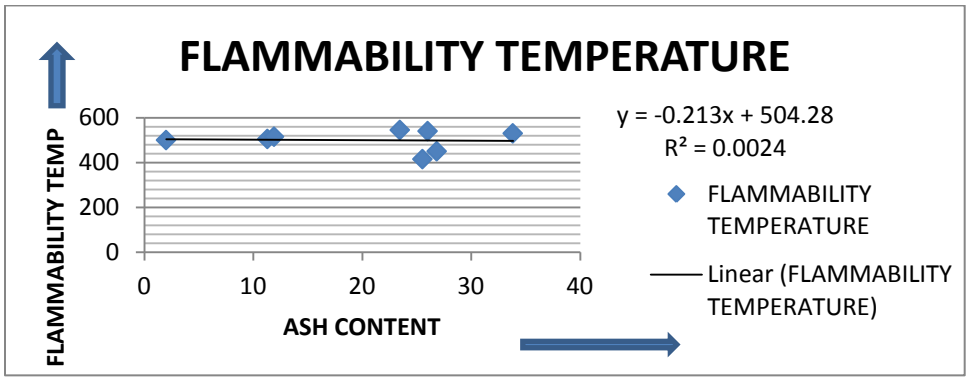



Fig no 5.1.4 Variation of Flammability temperature vs Ash Content

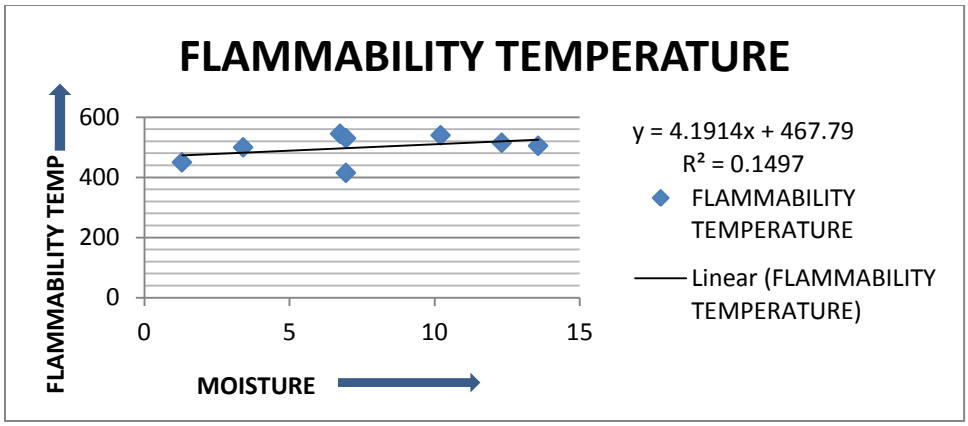



Fig no 5.1.5 Variation of Flammability temperature vs Moisture

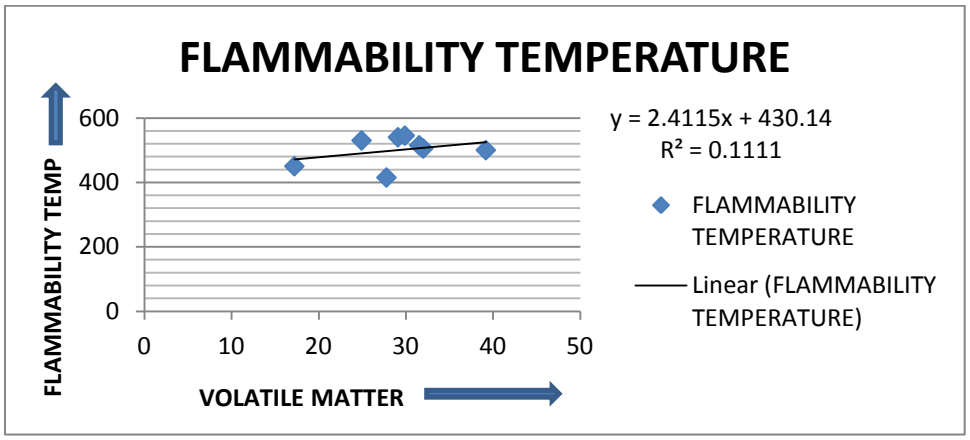



Fig no 5.1.6 Variation of Flammability vs Volatile Matter

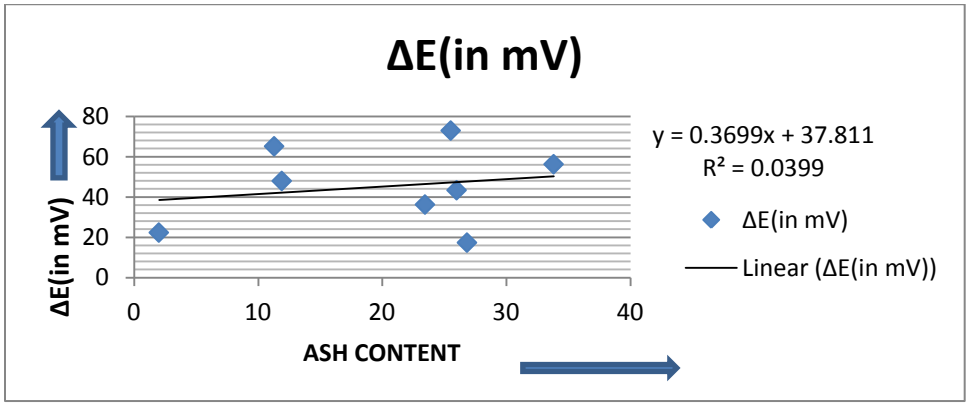



Fig no 5.1.7 Variation of ΔE vs Ash Content

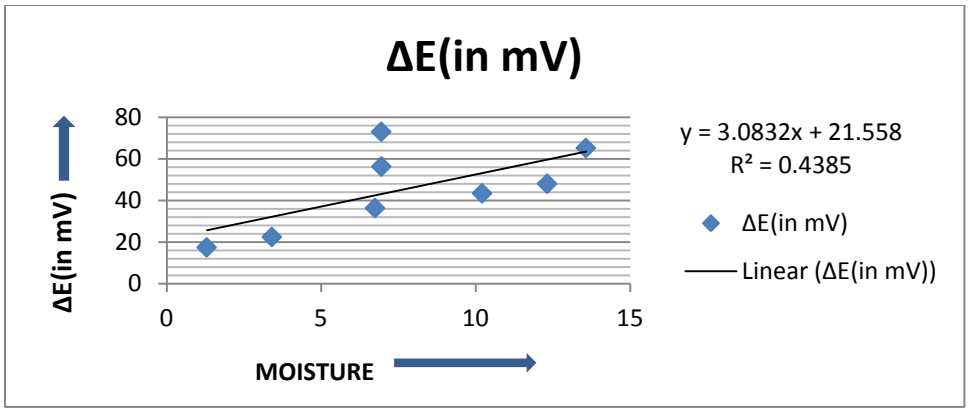



Fig no 5.1.8 Variation of ΔE vs Moisture

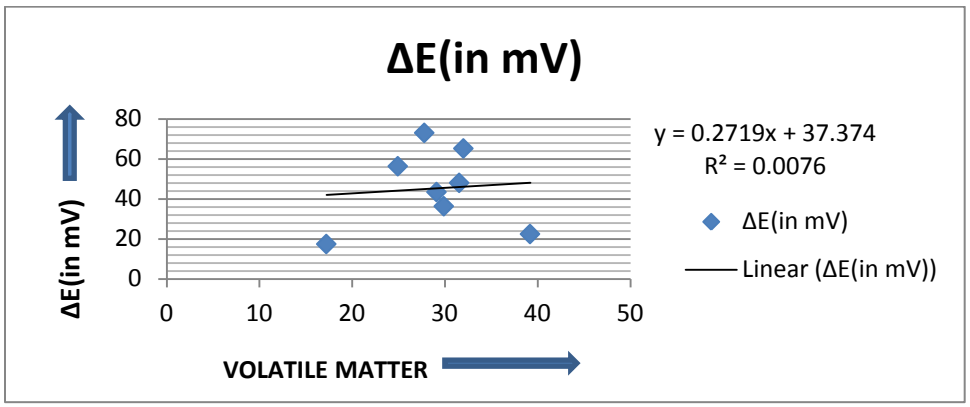



Fig no 5.1.9 Variation of ΔE vs Volatile Matter

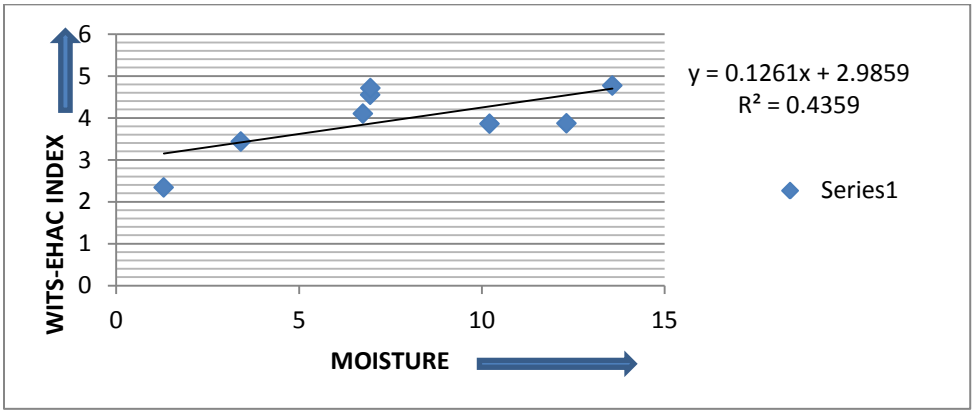



Fig no. 5.1.10 Variation of the WITS-EHAS vs Moisture

## 5.2 Conclusion

1. The results shown by Crossing Point Temperature value and Wet Oxidation Potential Difference value regarding liability of the coal samples towards spontaneous heating were quite similar. Both the experimental results suggested SCCL1 sample as highly susceptible and BCCL1 as least susceptible.

2.Wet Oxidation Potential Method showed productive results in determining spontaneous heating liability of coal samples showing similar results as CPT. Thus it can be used as a handy experimental tool in predicting spontaneous heating susceptibility of both high and low moisture coals. In addition to that it takes just 30 minutes for completion of the entire experiment in comparison to 2 hrs used in case of Crossing Point Temperature.

3.Flammability temperature cannot be considered as a sound experimental technique for determining spontaneous heating liability of various coal samples as it showed poor correlation with all the coal properties.

4.Both Wet Oxidation Potential Difference and Crossing Point Temperature showed high correlation value with moisture content of coal justifying their use in determining spontaneous heating liability of coal samples.

5. Crossing Point Temperature is used as a handy experimental technique in prediction of spontaneous heating liability in India but many a times it fails in predicting the spontaneous heating liability of high moisture coals. Also it is a time consuming process and reproducibility of similar results is seldom.

6. Wet Oxidation Potential Difference is an effective tool for determining spontaneous heating tendency for all types of coals and it produces faster results but still no proper guideline has been mentioned till date in order to standardise the potential difference values with respect to liability of coal towards spontaneous heating.

# Chapter 6

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